INTERNATIONAL HELLENIC UNIVERSITY

Estimation of the energy and environmental performance from the diffusion of solar conversion technologies in the built environment in EU

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SID:3304150002

SCHOOL OF SCIENCE & TECHNOLOGY

A thesis submitted for the degree of

Master of Science (MSc) in Energy Building Design

DECEMBER 2016

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ABSTRACT

This dissertation was written as a part of the MSc in Energy Building Design at the International Hellenic University. Its purpose is to estimate the potential energy savings and the emissions reduction for typical residential buildings over the last 10 years from the use of Domestic Solar Hot Water Systems (DSHWS) in countries of the European Union (EU).

The major parameters that were taken into consideration were the total installed glazed area of each country, the energy produced from a typical DSHWS and the emission factors of produced electricity along with the amount of energy produced by the DSHWS so as to provide an estimation of the quantity of Green House Gas (GHG) emissions that can be saved.

System Advisor Model (SAM) was used in order to make the calculations, find the optimum angle for the collectors according to the countries' latitude and the estimations for the energy savings and the emissions reduction.

The simulation results showed that as the latitude increases, solar fraction is decreasing. It ranges from 44,3% in Dusseldorf (51,28°) to 77,6% in Larnaca (34,88°). There is room for improvement for energy savings with Cyprus presenting the highest reaching almost 5,7% compared to its residential energy consumption. The quantity of CO_2 emissions saved was higher in Germany reaching almost 3,8 million tons of CO_2 taking into consideration the emission factors of produced electricity along with the amount of energy produced by the DSHWS and the installed collector area of each country.

Finally, for the completion of this dissertation I would like to express my gratitude to Dr. Georgios Martinopoulos for his useful guiding, scientific support and general contribution.

To Nancy

Sergios Bampalis

23/12/2016

CONTENTS

1.INTRODUCTION

Nowadays, the residential energy consumption has a large share of the final energy consumption regarding its use for space heating, cooking, lighting, electrical appliances and domestic hot water production. There is a consistent increase in the energy demand and the limited resources of fossil fuels along with the environmental problems their consumption causes, there is an essential need to shift towards renewable energy sources. EU has made some efforts by implementing policies for the reduction of GHG emissions and the promotion of renewable resources.

The purpose of this dissertation is to examine, analyze and estimate the potential energy savings and the emissions reduction by the implementation of DSHWS. By taking into account the total installed collector area of each country, the energy produced from a typical DSHWS and the emission factors of produced electricity along with the amount of energy produced by the DSHWS to provide an estimation of the quantity of GHG that can be saved. SAM was used for the calculations and the extraction of results for the estimation.

The dissertation consists of five chapters. In the first chapter, there is a general introduction to the subject and the aim of the dissertation. In the second chapter, there is an overview of the literature regarding the residential energy consumption, the policy measures of EU that are currently in action and the penetration of solar thermal markets in the residential sector. To that end, the dominant players of the market are analyzed and the types of DSHWS that are mostly used in the different countries along with relevant studies in order to result to the optimum technology for those kind of systems. Additionally, in the third chapter the methodology incorporated is presented, a brief explanation of the operation of SAM and the residential systems for domestic hot water usage. In the fourth chapter, the energy savings from the use of DSHWS are examined and the display of the simulation results and their parametric analysis. Chapter five, includes conclusions and comparison with the national goals set by each EU country and some potential prospects for the future.

2. LITERATURE REVIEW

2.1. INTRODUCTION

In this chapter, the energy consumption of the building sector in EU is examined taking into consideration its use. Space heating is one of the end-uses as well as cooking, lighting, electrical appliances and for domestic hot water production. With the assistance of ODYSSEE database, energy consumption is evaluated and analyzed in order to understand the important participation of the implementation of renewable energy in buildings and especially solar energy and the way it can contribute in the reduction of energy consumption in buildings.

Furthermore, the energy policies that are currently in action are examined as well as the EU directives that were passed in previous years. Moreover, solar thermal markets are analyzed in EU and the present situation of some important players (Member States) across Europe is discussed.

Finally, a brief discussion of the technology used in solar thermal collectors for domestic hot water production and the advantages and the disadvantages of each technology are presented together with the conclusions and the results of relevant studies.

2.2. ENERGY CONSUMPTION IN THE RESIDENTIAL SECTOR IN EU

Nowadays, buildings are one of the largest energy consumers with 32% of the total final energy consumption and around 40% in terms of primary energy consumption all around the world according to the International Energy Agency [1]. In general, new buildings consume less than 32-54 kWh/m^2 annually while older buildings consume 270 kWh/m^2 on average. In some cases, there are buildings that require up to 647 kWh/m^2 [2].

The building sector in Europe accounts for 40,7% of the total final energy consumption, which was 1.103,08 million tons of oil equivalent for 2013 of which 295,8 million tons in residential buildings and 152,3 million tons in non-residential buildings. Space heating accounts around 69% of the total household consumption while water heating 11% for 2013 [3]. Buildings are the major end-use sector, tailed by transport (32%), industry (26%) and agriculture (2%) in 2015. At European level, 66,6% of the consumption of buildings is for residential buildings [7].

At present, about 35% of the EU's buildings are over 50 years old. The total floor area of buildings is around 25 billion m^2 in the EU (2012), of which 75% in residential buildings. Single family houses account for 66.6% of the residential floor space [7].

During the years, final energy consumption decreased by 7% in the EU-28 in 2013. The reduction in final energy consumption was influenced by economic performance, structural changes in various end-use sectors, industry in particular, improvements in end-use efficiency and lower heat consumption due to better climatic conditions. Since 2005, energy consumption in the residential sector has started to decrease in the EU-28 after some small annually increases [4].

According to the ODYSSEE database the final consumption of the residential sector in EU is presented in Figure 1. In 2000 the final energy consumption in the residential sector began at 316,7 Mtoe, the highest reduction was in 2011 at 296,5 Mtoe reaching 300,3 Mtoe in 2013 [7].

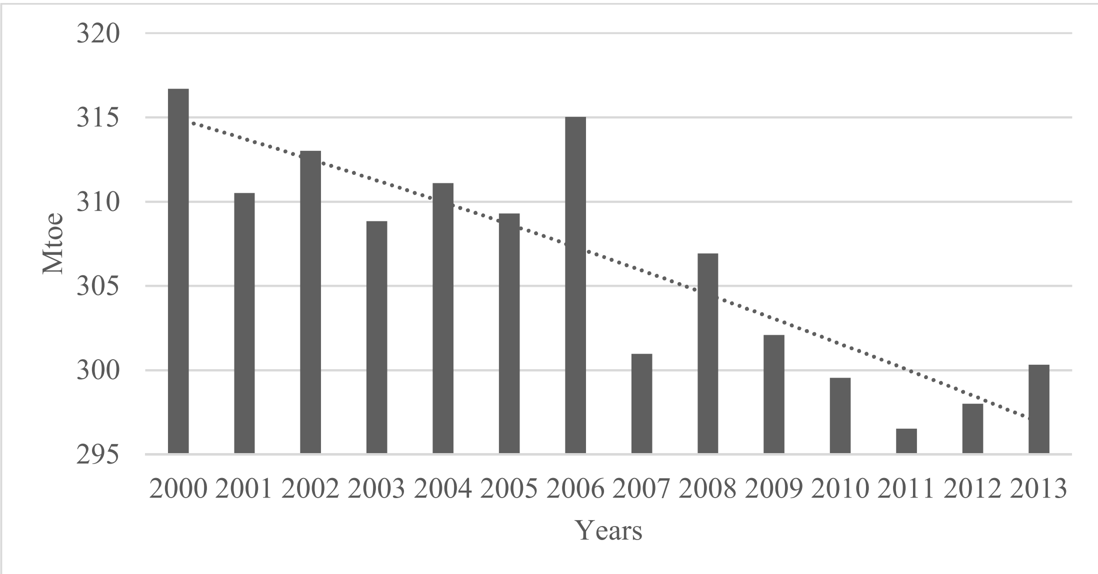

Figure 1: Final energy consumption in the residential sector in EU

While there is a rise in southern Europe due to heating comfort, there is a decrease of the average energy consumption per dwelling in 20 countries. The average dwelling size increased by 4% since 2000 at EU level reaching 87 m^2 per dwelling. Especially in Eastern European countries had an increase of 10% and this had as a result, energy consumption per dwelling to be reduced marginally less than 2%/year per m^2 in the EU. The noticed improvement in energy efficiency was a result of better thermal performance of buildings, more efficient electrical appliances (air conditioning) and heating systems (condensing boilers and heat pumps). Still, part of this improvement was counteracted by a growing number of electrical appliances, larger homes and the dispersion of central heating. The mutual result of those influences was an escalation in the average consumption per dwelling by 0,4% per year, compensating 60% of the energy efficiency development reached through technological modernization [6].

As shown in Figure 2, the energy consumption per dwelling started from 1,7 toe/dw in 2000. The first large reduction was in 2007 that accounted for 1,5 toe/dw and it continued decreasing until 2013 that reached 1,42 toe/dw.

The additional factors responsible for the decrease of the unit consumption should be attributed to the retrofitting of existing dwellings and the introduction of new more efficient heating appliances (condensing boilers and heat pumps) [6].

The impact of regulations for new buildings on the decrease of the average energy consumption per dwelling differs between countries, relying on the number of building code upgrades, their strictness and the volume of construction. One of the major contributors in increasing household energy consumption is the expanding number of dwellings due to the population growth and the growing number of one person households in some countries [7].

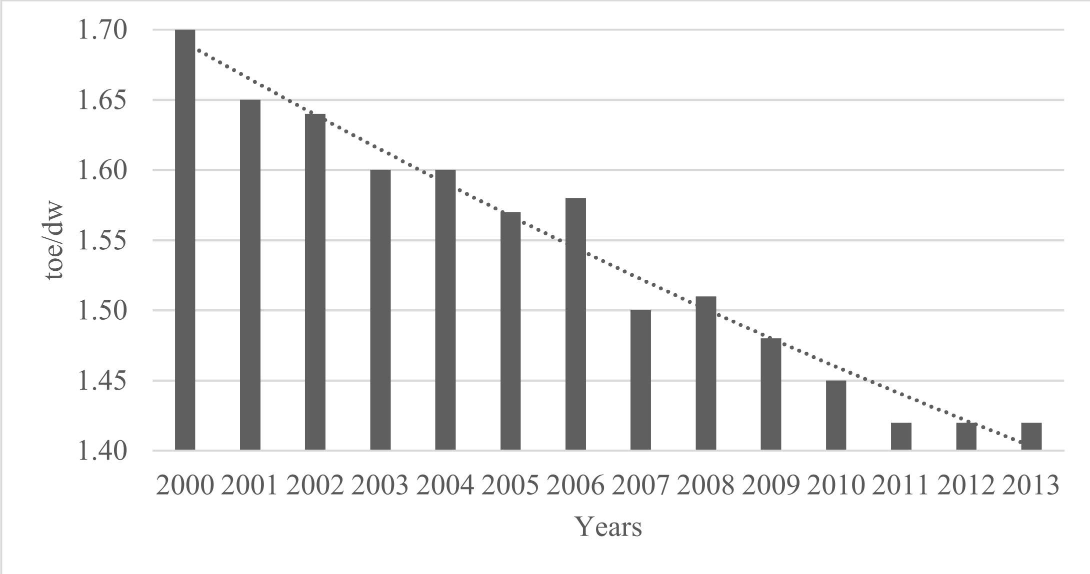

Figure 2: Consumption per dwelling in EU

Nonetheless, energy savings, deriving from energy efficiency improvements in the various end-uses, supported to reduce household energy consumption by 60 Mtoe between 2000 and 2012. The energy consumption of households would have been 60 Mtoe higher without these savings. The rate of savings has slowed since the financial crisis in EU for an average value of 66.291 GWh/year before 2008 to 41.868 GWh after. Furthermore, alterations in heating behavior also had an effect on the energy consumption by decreasing it by 232.600 GWh. This behavioral impact is attributed to the combined effect of price escalation and of the economic recession as consumers paid more attention to their heating expenses and have decreased their level of comfort. The level of this behavioral impact has doubled since 2008, to 30.238 GWh/year compared to 13.956 GWh before [7].

In Figure 3, the heating consumption per m^2 was 14,5 koe/m^2 in 2000. It started reducing afterwards and especially after 2008 resulting at 10,81 koe/m^2 in 2013.

The EU average annual specific consumption per m^2 for all kinds of buildings was 210 kWh/m^2 in 2012. Non-residential buildings are on average 55% more energy intensive than residential buildings (286 kWh/m^2 compared to 185 kWh/m^2) because lighting is used for much more time and despite the fact that there may be no cooking or refrigerators, space heating and cooling have an important role in the energy consumption [7].

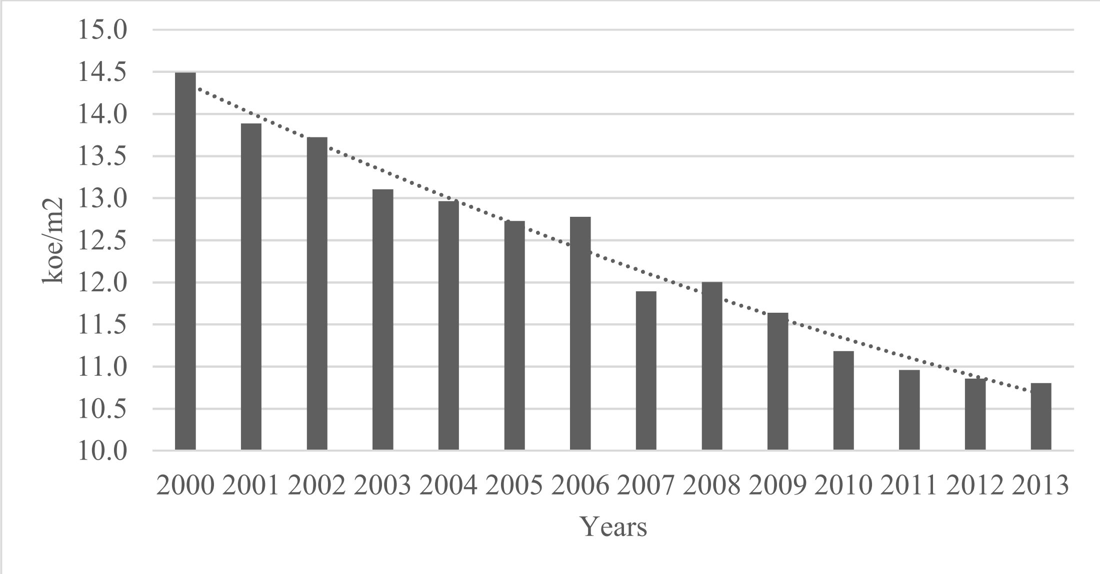

Figure 3: Heating consumption per m^2 in EU

In Figure 4, the consumption for space heating is presented. From 2000 to 2013 a 20% reduction has been achieved.

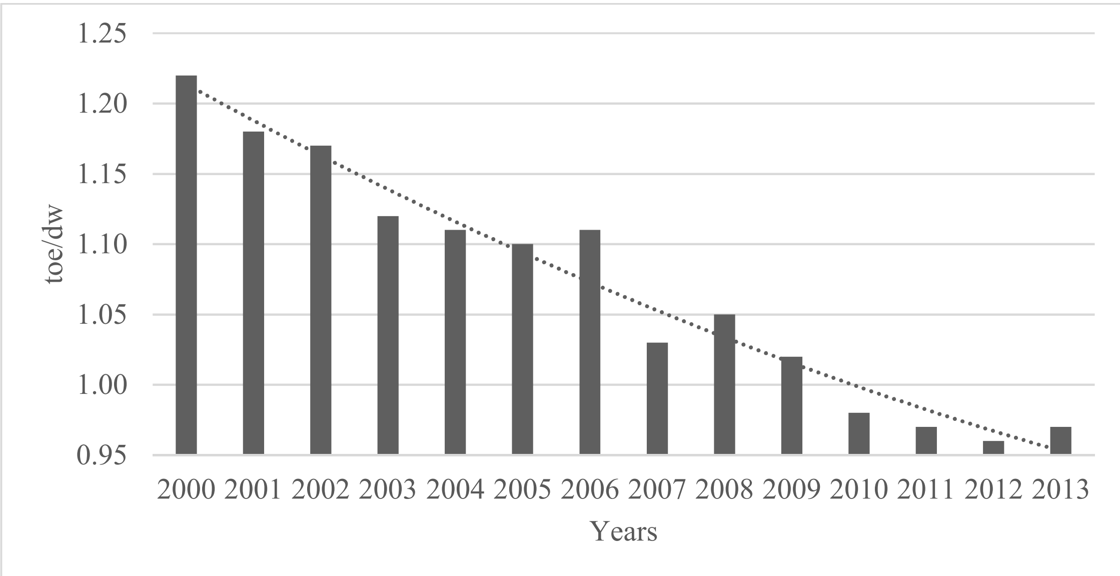

Figure 4: Consumption for space heating per dwelling in EU

The average electricity use of EU residential buildings is 4.000 kWh. Almost 2.300 kWh have to do with captive uses of electricity such as electrical appliances, lighting and air conditioning.

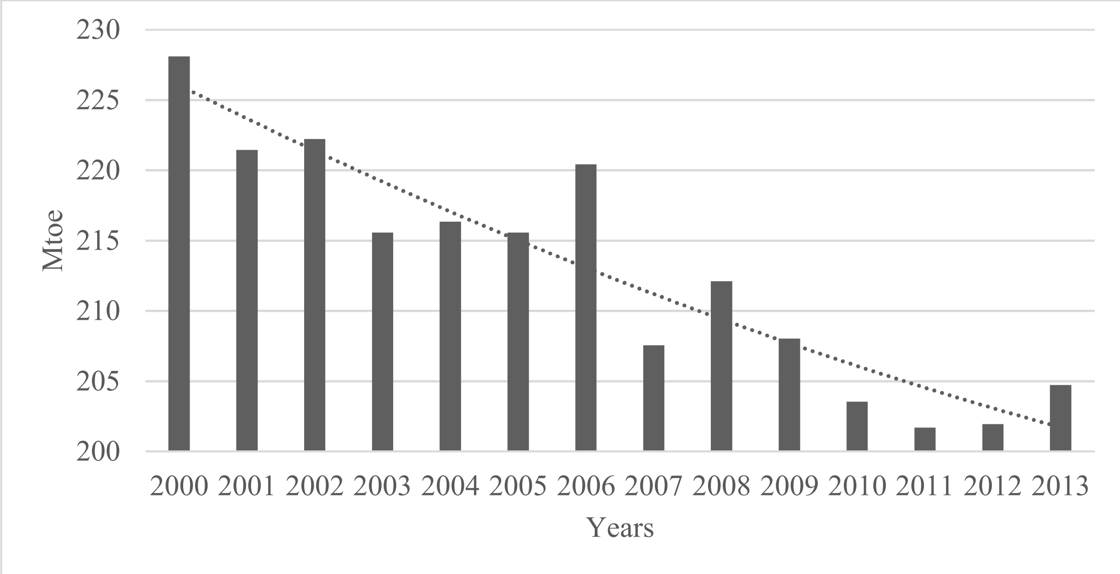

Figure 5: Final consumption of residential for space heating in EU

As it is shown in Figure 5, the decrease of final consumption for the residential sector regarding space heating had a major drop from 228 Mtoe in 2000 to 207,55 Mtoe in 2007 and then continued in a declining trend ending in 204,73 Mtoe in 2013.

The decreasing trend in household energy consumption is detected in most EU countries, with a very robust decrease since 2008, by above 4%/year, in some countries like Ireland, Cyprus, Portugal, Luxembourg and Malta [7].

The introduction of new dwellings with improved insulation assisted in reducinge the unit consumption per dwelling at different levels: 12% for Sweden, 35% for France and Netherlands, 40% for Poland, 50% for Denmark and 70% for Germany [6].

There is a decrease of the heating consumption per m^2 in all countries, except in Italy and Finland. There are member countries such as Romania, Slovenia, Latvia and Slovakia in which the decline can be attributed to higher price and energy efficiency improvements of buildings [5].

There is a difference in annual specific consumption per m^2 among EU countries. For example, it is 80% lower in South Europe (Bulgaria, Spain) than in North Europe (Finland). Such variations are partially explained by climatic conditions and statistical definitions. It is higher in Norway, Sweden, Finland and France, because of the use of electricity for space heating, 32% for Finland, 25% for Sweden and 22% for France in distinction to 9% for Denmark and 4% for Netherlands in 2012. After adjustment to the EU average climate, Luxembourg and Belgium prove to have the highest consumption, at 23.000 kWh compared to 9.300 kWh in Portugal and Bulgaria and even 3.500 kWh in Malta [7].

The consumption for captive uses differs expressively among countries, from 1.500 kWh for Romania and the Baltic countries to 3.800 kWh for Cyprus, Malta, Sweden and Finland and even 4.600 kWh in Norway [7].

There are important differences among EU countries from 60-90 kWh/m^2 in southern countries with lower heating needs (Malta, Spain, Bulgaria, Greece and Croatia) to 175-235 kWh/m^2 in colder countries such as Estonia, Latvia and Finland. In Malta, Cyprus and Portugal the share of space heating is under 30% and under 50% in Spain. Water heating is second with a quite steady share (13%) and electrical appliances are having a larger importance with their share increased from 9% to 11%. Cooking, lighting and air conditioning represents 6%, 2% and 0.5% of total respectively [7].

By amending the energy efficiency of buildings, it could decrease total EU energy consumption by 5% to 6% and lower CO_2 emissions by about 5% [2]. The energy consumption of buildings varies across EU countries because of the residents' behavior, the climatic conditions, the fuel mix of different EU countries, the market penetration of renewable energy systems and especially the solar technologies. Energy consumption of a building depends on the heating and cooling demand, the electrical appliances used, the lighting and the domestic hot water usage.

2.3. ENERGY POLICY IN EU

The evaluation report of the Intergovernmental Panel on Climate Change (IPCC) in 1990 together with the adoption of the Kyoto protocol in 1997 motivated the executive body of EU, the European Commission (EC) to establish a common path regarding important strategic issues for climate change and energy security in early 2000s. A necessary concept of energy policy was approved at the meeting of the European Council in London in 2005. In 2007, "An energy policy for Europe" of the EC's strategy characterized the creation of an action plan that established the three major challenges for European energy policy, forming the core of the common energy policy: sustainability, security of supply and competitiveness. In the direction of achieving these goals, the commission laid out quantifiable targets, the famous

20/20/20 targets up to 2020. The action plan was completed with changes in legislation shortly afterwards with the Lisbon Treaty (2007) finally including specific provision on energy [8].

European policy establishment follows the important political principles of subsidiarity, proportionality and better regulation as described in Treaties and political statements. The goal is to secure that policies are developed in a democratic, transparent and representative way with clear justifications and balanced assessment of options. Impact assessments follow all legislative proposals summarizing advantages and disadvantages of different policy actions. New energy policy proposals are created on the basis of wide stakeholder hearings including national authorities, regional bodies, industrial associations, companies, consumers as well as associations and non-governmental organizations. EU energy policy actions will always comply with two main principles: Firstly, Member States are in charge of their national energy mix and secondly, domestic energy resources are a national resource [8].

Since the building sector accounts for 40% of total energy consumption in the EU and it is increasing, the decrease in energy consumption and the diffusion of renewable energy resources are important measures in order to reduce EU's energy dependency and GHG emissions [10]. By reducing the energy consumption of buildings, a direct reduction of the associated GHG emissions will be obtained and a faster and cheaper implementation of renewable energy sources will be triggered [16]. Improving the energy performance of buildings is a cost-effective way of fighting against climate change and improving energy security [18, 19, 20].

The Energy Efficiency Directive 2012/27/EU (EED) [11] repealed both the Energy Services Directive (2006/32/EC) [12] and the CHP Directive (2004/8/EC) [13] in 2012 [7]. The EED sets up a mutual framework of procedures for the promotion of energy efficiency within EU so as to guarantee the accomplishment of the 2020 20% target on energy efficiency and to pave the way for further energy efficiency developments. The EU's energy consumption should not exceed 1,47 Mtoe primary energy consumption or 1,08 Mtoe of final energy consumption in 2020.The EED focuses on households and the services sector in several different ways and new measures are recommended [7].

The strategies of EU countries are part of their National Energy Efficiency Action Plans and Annual Reports (NEEAP) where they determine an overview of the country's national building stock. Moreover, they single out key policies that the country aims to use to inspire restorations and they provide an evaluation of the expected energy savings that will derive from restorations.

According to the Energy Performance of Buildings Directive (EPBD), Member States should establish policies and measures to stimulate the transformation of buildings that are rehabilitated into nearly zero energy buildings (nZEB). It also sets a 3% annual restoration target for buildings owned and occupied by central government [7].

Net zero energy building is a building with zero net energy consumption and zero carbon emissions yearly [15]. The idea of Zero Energy Building (ZEB) has earned deep international attention and is appreciated as the future target for the design of buildings. Nevertheless, the ZEB concept requires a clear and consistent definition before being fully implemented in the national building codes and international standards [15].

The recast of the Energy Performance of Buildings Directive (EPBD, 2010/31/EU) [10] abolished the corresponding earlier directive from 2002. The earlier directive presented energy efficiency certificates and obligated enhanced building regulations. The recast directive introduced new challenges like moving towards new and reconstructed nearly-zero energy buildings, the implementation of a cost-optimal methodology for setting minimum requirements for the envelope and the technical systems and inquiries of heating and air-conditioning systems [7].

The Member States are obliged to make certain that all new buildings will be nearly-zero energy buildings (nZEB) by the end of 2020 and by the end of 2018 in the case of public buildings [7]. Nearly-zero buildings have been expected to consume on average 40% less energy than buildings constructed in 2012 (in a range of 20-60%) (Concerted Action EPBD 2013).

The trend towards nZEB will not only advance energy efficiency but also enhances the use of renewable energy in buildings as the definition of nZEB [7]. It is mentioned that: “The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby”.

The Renewable Energy Directive covers large scale renewable energy production, as part of the energy supply sector, as well as small scale production at the end-users place [14]. Member States will introduce in their building requirements and codes suitable measures in the direction to increase the share of all kinds of energy from renewable sources in buildings [7].

In establishing such measures or in their regional support schemes, the Member States may consider national measures linking to substantial increases in energy efficiency and relating to cogeneration and to passive, low or zero-energy buildings [7].

Beyond 2020, EU countries have already arranged a new renewable energy goal of at least 27% of final energy consumption in the EU as a whole by 2030 which goal is part of the EU's energy and climate goals for 2030 [9].

At present, renewable energy, mostly biomass represents 14% of total final consumption of households at the EU level and it is developing rapidly. The largest shares are detected in countries with low income and large wood resources: it is around 45% in Latvia, Romania and Estonia, and 30% in Slovenia, Lithuania and Bulgaria. Denmark has the highest development, followed by Estonia, Slovenia, Bulgaria, Romania and Finland [7].

At the EU level, the share of renewables in household consumption represents 19%, of which 13% is for biomass and 6% for renewable electricity and heat. As far as the share renewables in the production of electricity and heat is concerned, the highest portion is observed in Norway (over 90%) driven by hydropower, followed by Latvia and Sweden 60% [7].

2.4. SOLAR THERMAL MARKETS IN EU

Solar energy is promoted in many countries to replace conventional technologies currently used to produce hot water. Solar water heaters can be a good economic and environmental solution mostly for southern countries which have advantage of good solar irradiation [6]. Solar water heaters installed capacity increased in many countries through financial incentives such as subsidies, soft loans or tax credits and regulations making the installation of solar heaters compulsory in new construction or main restorations like Spain, Greece and Portugal. Austria is the benchmark among countries with medium solar radiation with 20% of dwellings equipped by 2012 while around 75% of dwellings have solar water heaters in Cyprus and 30% in Greece [7, 17].

In 2003, 80% of the EU market was concentrated in only 3 countries (Germany, Austria and Greece) [21]. The capacity in operation reached 13,6 million m^2 of collector area at the end of 2004, which provided an estimated 8.164 MWh of clean energy and the newly installed capacity reached 1,55 million m^2 of collector area [22]. At the same time, the growing market share of combisystems that produced not only domestic hot water but also supported space heating led to higher energy savings. This system type was used in Northern and Central Europe, especially in Austria they had a market share of 35% and the market almost passed the 2 million m^2 mark of collector area of new capacity [23]. The effects of the 2008/2009 financial crisis were presented by very low renovation rates and collapse of new build developments, preventing the solar thermal sector from taking full advantage of the European trend towards more demanding standards for the energy performance of buildings [25]. In 2009, the market decreased by 10% and the market reliance on Germany (38% of EU) decreased with Austria, France, Greece, Italy and Spain together accounting for 39%; the other countries represented 23% of the market and became relevant, showing a clear trend for fast growth. In 2013, it continued increasing and reached 43,1 million $m^2$of collector area showing an increase of 6,2% but the newly installed capacity was 3,05 million m^2 of collector area representing a decrease of 11,8%. Germany, led the decline with a decrease of 11%, totaling 1,02 million m^2 of collector area. France experienced the strongest decrease (-24%), while in the medium size markets Portugal was the most affected (-31%) [29]. Finally, in 2014 the total installed capacity increased and reached 45.4 million m^2 of collector area representing an increase of 5,3% which is presented in Figure 6. Greece and Spain grew by 18,9% and 9,8% respectively. On the other hand, the market, underwent a reduction in the newly installed capacity amounting to 2,9 million m^2 of collector area representing a decrease of 7.1% as presented in Figure 7 [30].

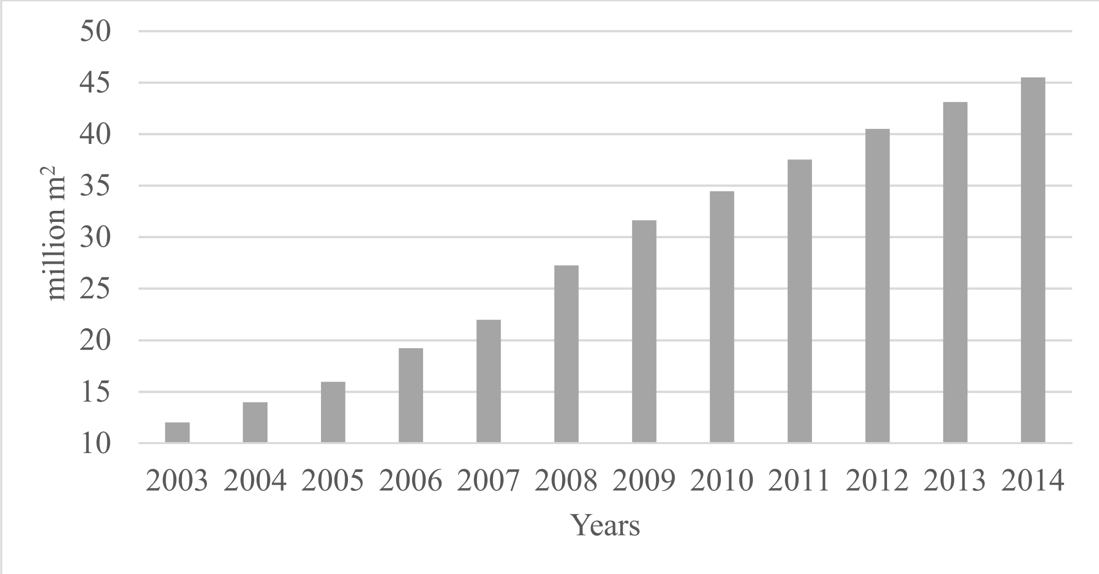

Figure 6: Total glazed area in operation in EU

As presented in Figure 6, the total glazed area in operation started at almost 12 million m^2 of collector area in 2003 and has been growing over the years. Even during the financial crisis, it was 31,62 million m^2 of collector area in 2009 and in 2014 it reached 45,48 million m^2 of collector area.

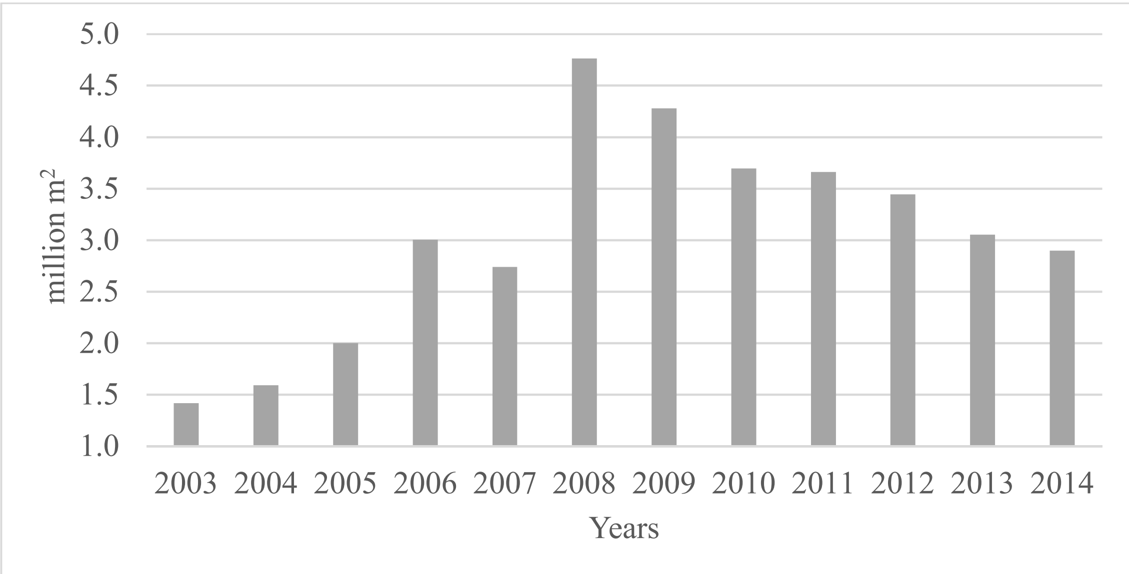

Figure 7: Total newly installed glazed area in EU

The total newly installed capacity is presented in Figure 7. In 2003, it was 1,41 million m^2 of collector area and was increasing until the crisis of 2009 that reached 4,27 million m^2 of collector area. Ever since it was reduced to end up at 2,89 million m^2 of collector area in 2014.

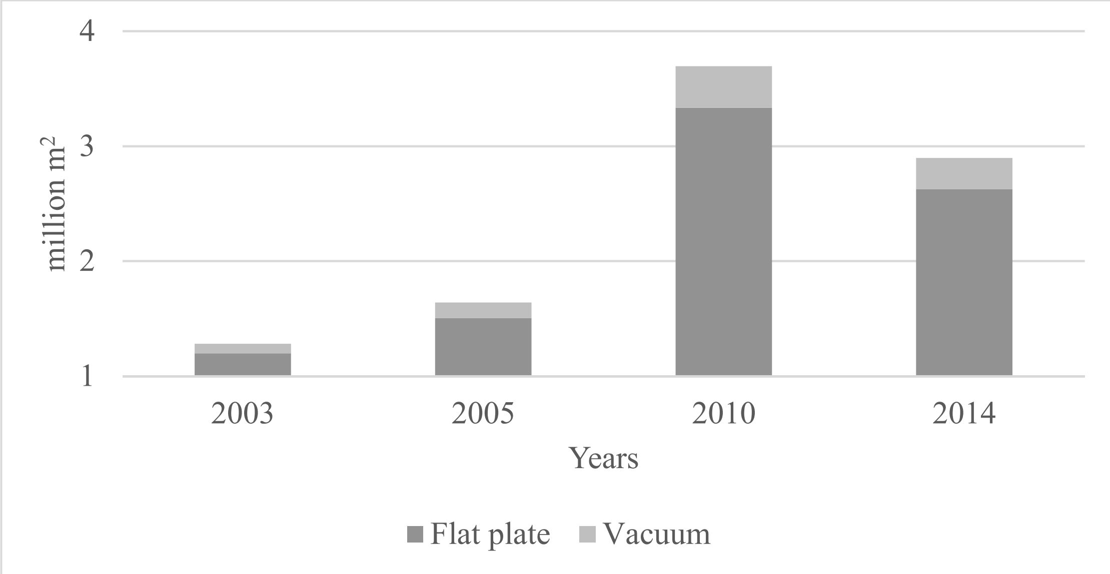

Figure 8: Flat plate and vacuum collectors in EU

Flat plate collectors have dominated the solar thermal market against vacuum collectors as can be seen in Figure 8. Only in 2010 the amount of vacuum collectors had a significant share of 10%.

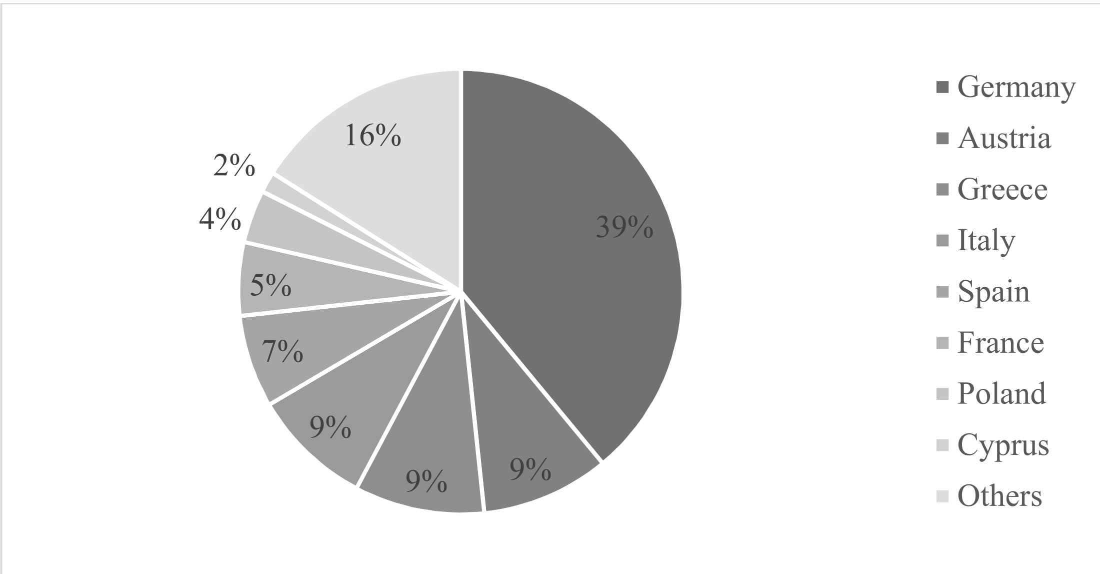

Figure 9: Total installed glazed area of EU countries in 2014

As evident, in Figure 9, Germany is the key player in total installed capacity with a 39% share in 2014. Austria, Greece and Italy follow with a 9% share.

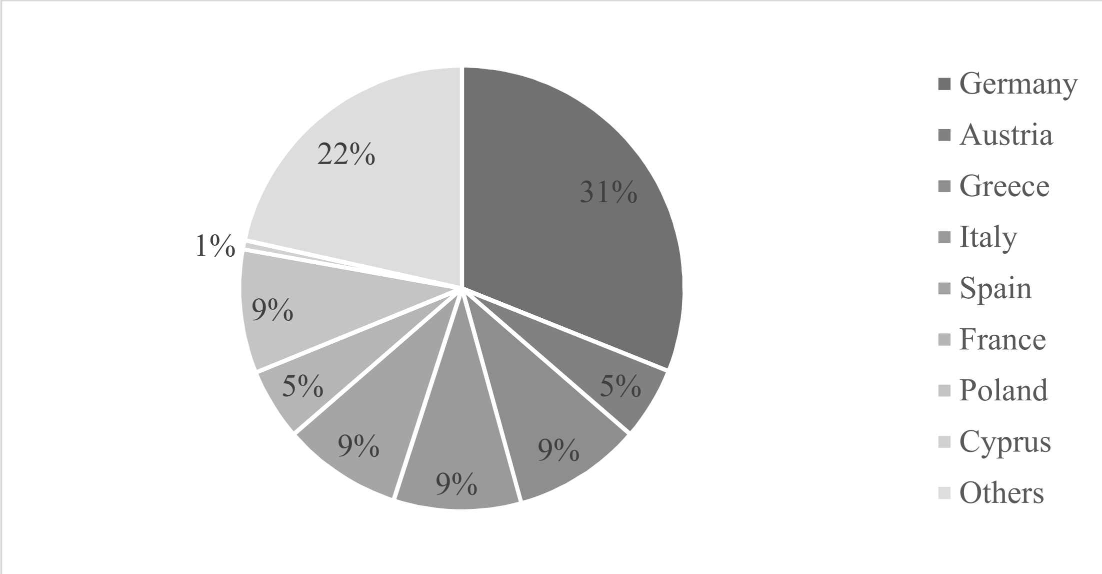

Figure 10: Total newly installed glazed area of EU countries in 2014

From Figure 10, it is apparent that the same countries dominate newly installed area with the exception of Poland.

In the following paragraphs a brief overview of the major markets is examined and analyzed according to their total installed area share.

2.4.1. GERMANY

Germany experienced a growth of 39% in 2003 because of the start of a new public awareness campaign, growing oil prices and the increase in the federal incentive program, with record application numbers [21]. Almost 50% of the EU's new capacity was installed in Germany with 750.000 m^2 of collector area the 2004 sales exceeded those of the previous year by 4% [22]. During 2005, 950.000 m^2 of collector area of new capacity were installed that represented a growth of 27% [23]. The impact of the crisis was felt more sharply in Germany market. In 2009 the market decreased by 23%, remaining at 1,61 million m^2 of collector area and the market development was affected by both lower fossil fuel prices and declining end-user investments [25].

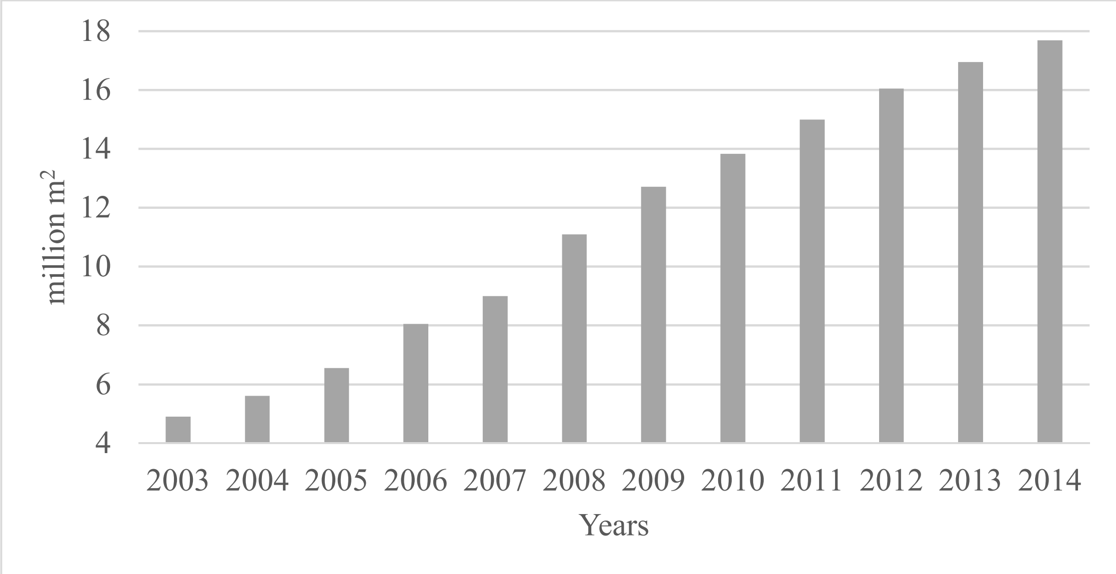

Figure 11: Total glazed area in operation in Germany

The market dropped by almost 29% in 2010 with 1,15 million m^2 of collector area of newly installed capacity [26]. Only 1,02 million m² of collector area were newly installed but the total installed capacity reached 17,5 million m² of collector area representing an increase of 5,8% [29].

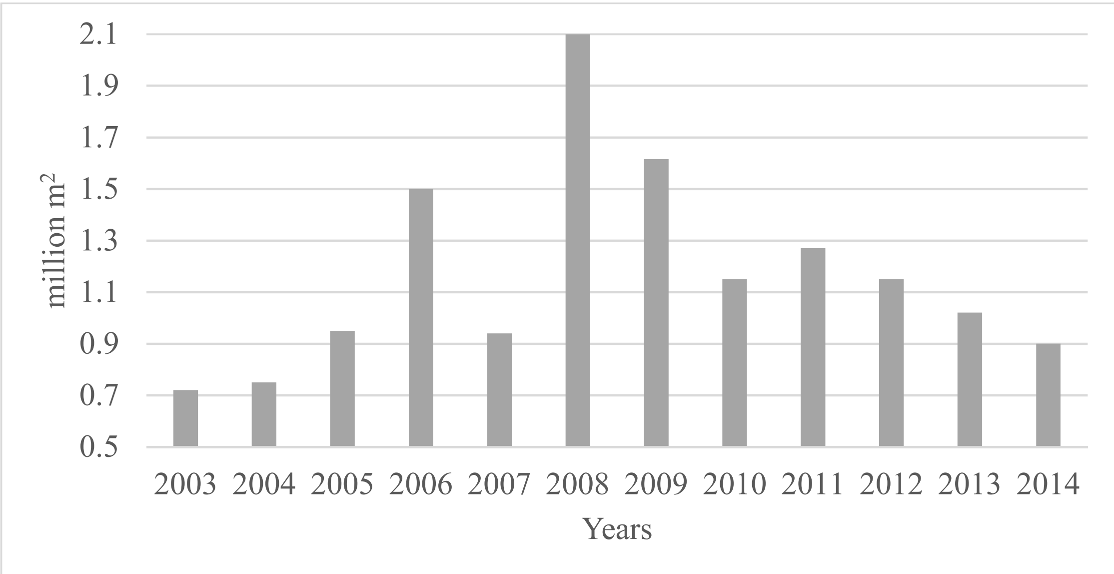

Figure 12: Total newly installed glazed area in Germany

In 2014, with 0,9 million m² of collector area newly installed, the market has slipped back to past levels but the total cumulated area grew approximately to 18,4 million m² of collector area. A decrease of 12 % from year to year reveals that both the technology and the market face major difficulties in Germany. The average size per installed system has continuously decreased to around 5 m² for hot water systems [30].

In Figure 11, the growth of total glazed area in operation in Germany is presented. It started at 4,9 million m^2 in 2003 and reached 17,6 million m^2 of collector area in 2014.

As presented in Figure 12, until 2006 the newly installed glazed area was growing and reached to 1,5 million m^2 of collector area. There was a decrease in 2007 at under 940.000 m^2 and in 2008 it reached to 2,1 million m^2. After this, the reduction continued until 2014 that marked 900.000 m^2 of collector area.

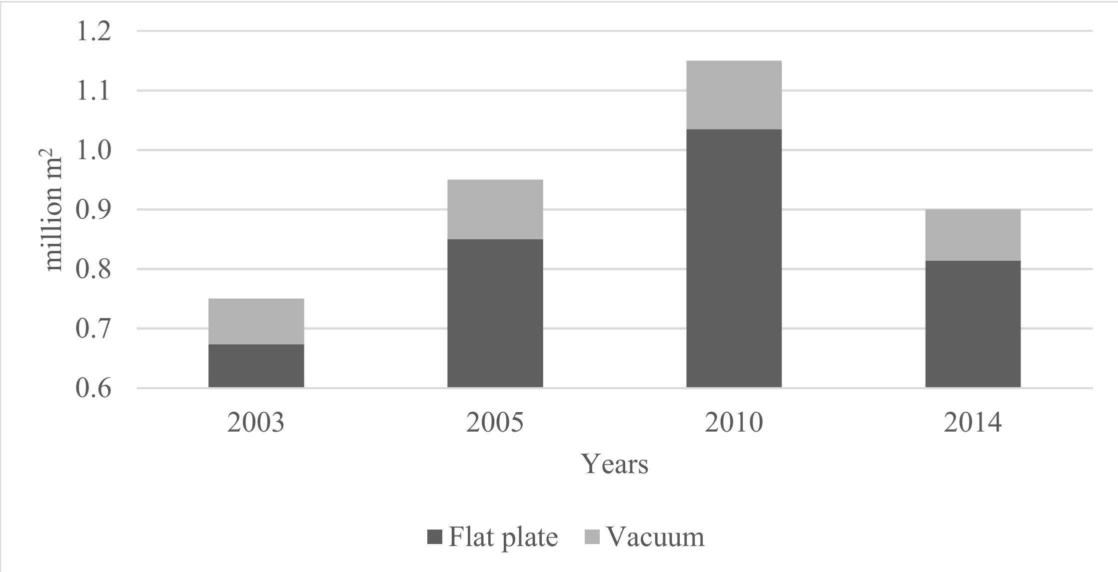

Figure 13: Flat plate and vacuum collectors in Germany

As presented in Figure 13, flat plate collectors had the major amount of Germany market but in 2005 and 2010 the vacuum collectors represented 11% and 12% respectively.

2.4.2. AUSTRIA

In 2003, Austria resumed trends of growth [21]. During 2004, 9% more solar thermal capacity was built with 182.594 m^2 of collector area [22]. The market experienced growth of 28% with 233.000 m^2 in terms of newly installed capacity. Austria was also the leading market for solar combisystems in 2005[23]. During the difficult year of 2009, showed a small growth of 3% and the newly installed capacity increased to 356.500 m² of collector area [25]. The Austrian market was facing difficult times, with sales declining for the fourth consecutive year. In 2013, the decline corresponded to 13% in comparison with the previous year and the newly installed capacity amounted to 189.000 m² of collector area [29]. In 2014, the investments in renewable heating systems were facing competition from a strong and successful marketing campaign for gas and oil heating systems with attractive financial grants from the oil associations, the electricity lobby who supported heat pump and PV systems [30].

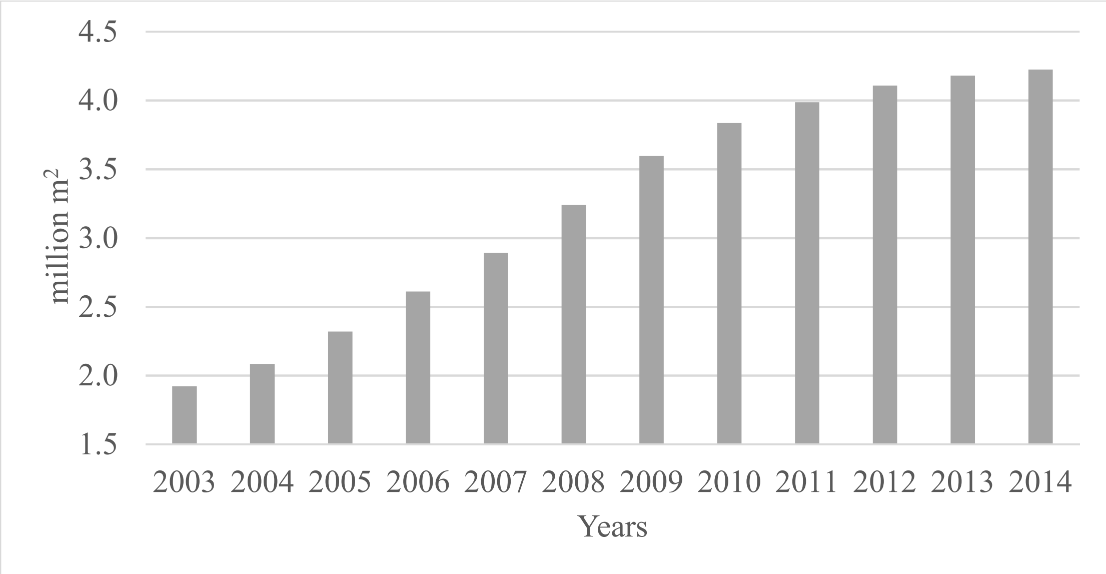

Figure 14: Total glazed area in operation in Austria

In Figure 14 it is shown that the total glazed area in operation started at 1,92 million m^2 in 2003 and has continually growing up to 4,22 million m^2 in 2014.

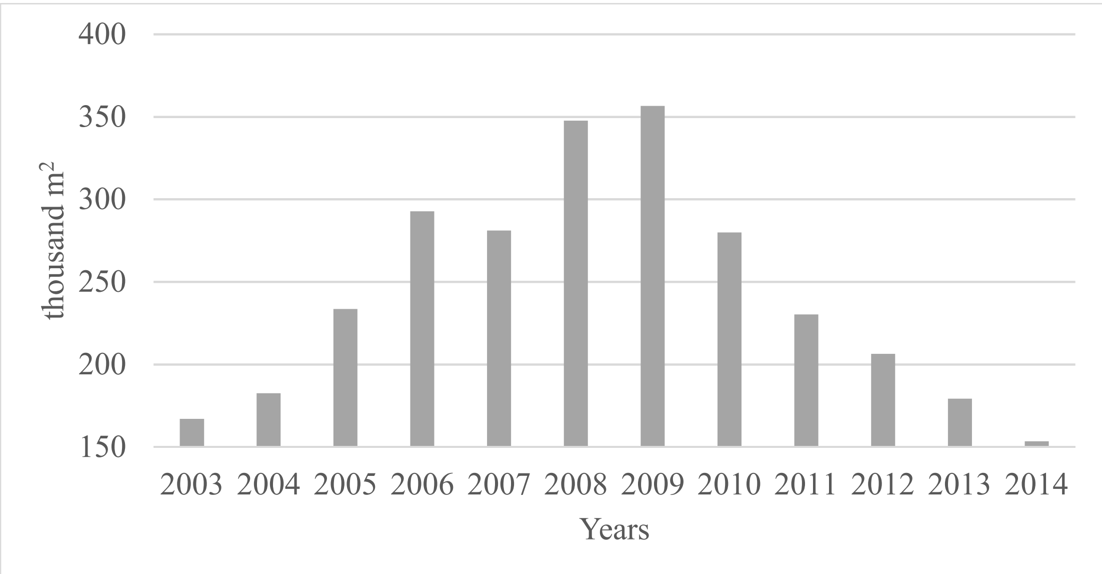

Figure 15: Total newly installed glazed area in Austria

As presented in Figure 15, the total newly installed capacity began increasing in 2003 and reached at 292.669 m^2 of collector area in 2006. In 2007, it had a small reduction and then in 2008 an increase that lasted until 2009 that reached 356.544 m^2 of collector area. From then onwards, a large decline followed and in 2014 it marked almost 153.440 m^2 of collector area.

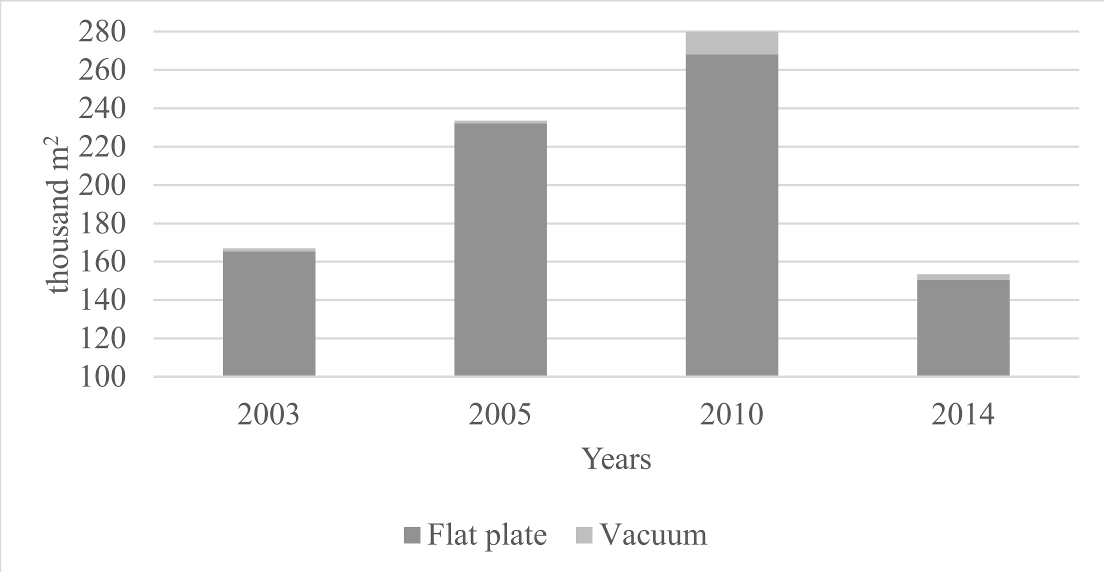

Figure 16: Flat plate and vacuum collectors in Austria

Flat plate collectors in Austria had the largest share of the market except for 2010 that vacuum collectors managed to take a good piece of 4% as presented in Figure 16.

2.4.3. GREECE

In 2003, Greece had a growing trend in the solar thermal market [21]. Greece has replaced Austria in second place in the EU's solar thermal market with 215.000 m^2 of collector area of new solar thermal capacity being installed in 2004 representing an increase of 34% [22]. In 2005, the newly installed capacity was 220.500 m^2 of collector area and the total capacity in operation marked 3.05 million m^2 of collector area [23]. During 2009, the Greek market has contracted dramatically by almost one third, from approximately 300.000 m^2 to 206.000 m^2 of collector area. The support schemes, covering energy efficiency measures and replacement of older heating equipment, proved to be poorly funded and rather ineffective for the solar thermal sector [25].

The newly installed capacity for solar thermal products slightly increased in 2010 with a growth of 3,9% the market reached 214.000 m² of collector area of newly installed capacity [26]. After withstanding the overall crisis for some years, the newly installed capacity decreased by 7%, amounting to 227.150 m² of collector area.

The new housing market remained flat, not creating opportunities for new installations. The market counted 4,2 million m² of collector area representing an increase of 1,4% [29]. The Greek solar thermal market grew by 18,9% and the newly installed capacity totaled 270.000 m² of newly installed collector area. Greece reached a total installed capacity of 4,3 million m² of collector area representing an annual increase of 2,6% [30].

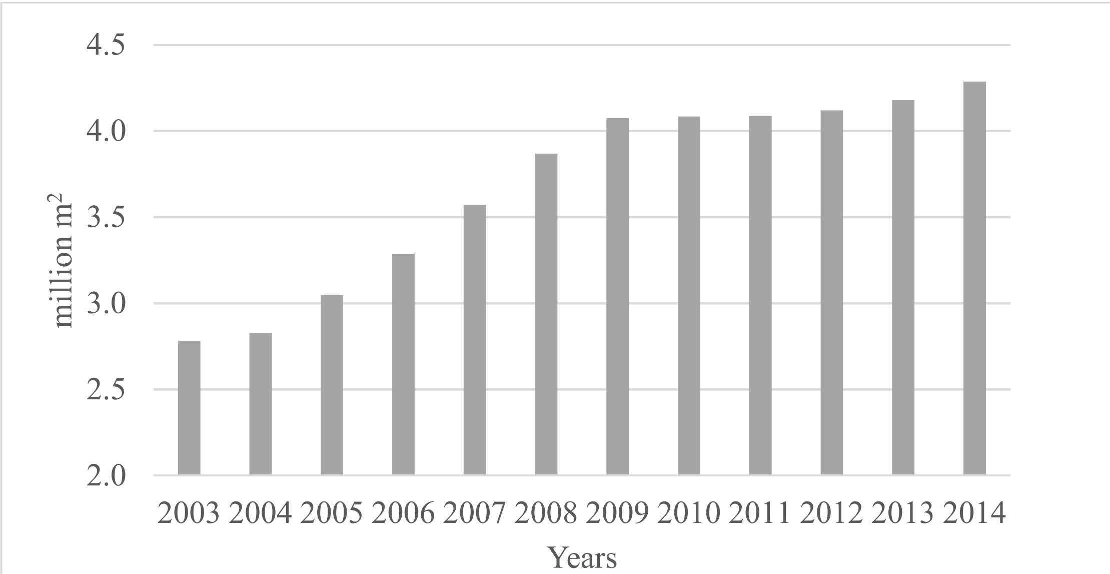

Figure 17: Total glazed area in operation in Greece

As presented in Figure 17, the total glazed area in operation was almost 2,8 million m^2 of collector area in 2003 and continued growing up until 2009 that reached 4,07 million m^2 of collector area. Then it pretty much remained steady with small increases and in 2014 marked 4,28 million m^2 of collector area.

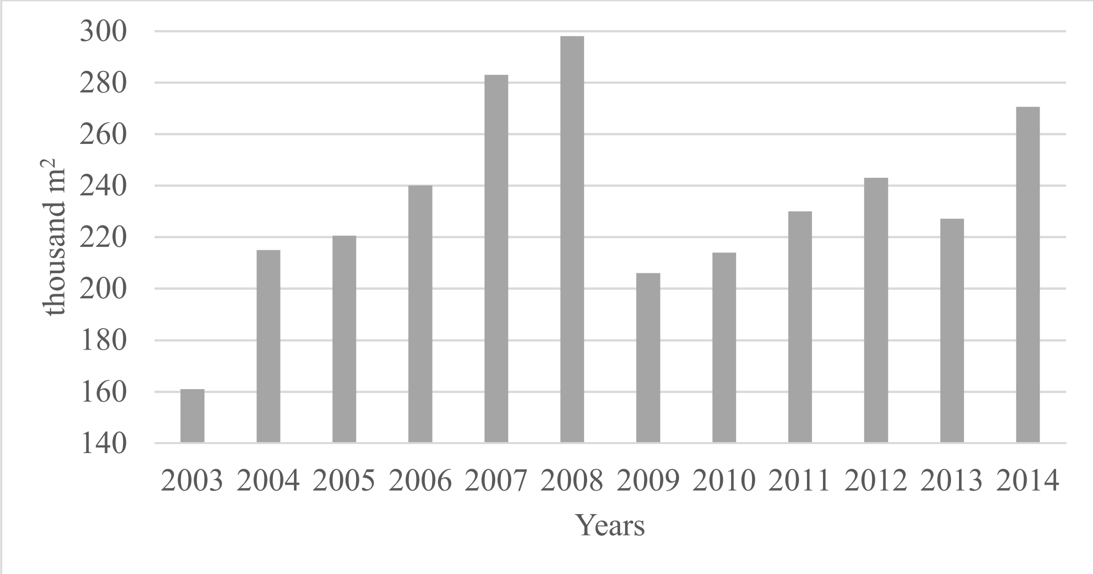

Figure 18: Total newly installed glazed area in Greece

From Figure 18 it is apparent that the total newly installed glazed area has been growing since 2003 that began from 161.000 m^2 of collector area until 2008 that marked 298.000 m^2 of collector area. Then, there was a large decline that reached to 206.000 m^2 of collector area in 2009 but afterwards it kept increasing with a small reduction in 2013 and in 2014 the newly installed area reached above 270.600 m^2.

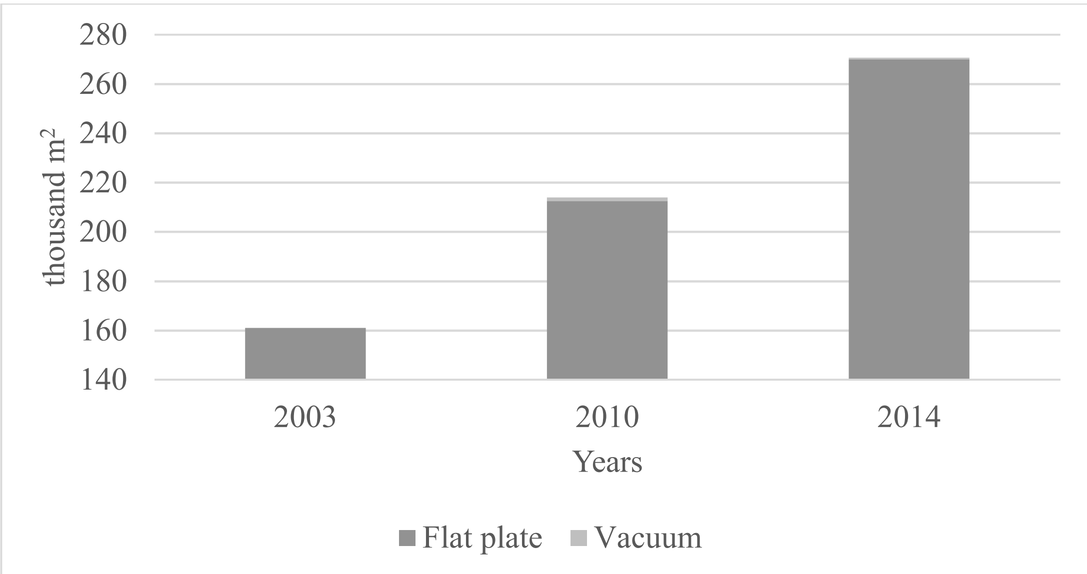

Figure 19: Flat plate and vacuum collectors in Greece

As presented in Figure 19, in the Greek solar thermal market, flat plate collectors had almost the whole share of the market.

2.4.4. ITALY

In 2003, Italy had only 50.000 m^2 of collector area of newly installed capacity and the total glazed area in operation was 398.785 m^2 [21]. The total installed capacity was 444.285 m^2 and had an increase of 58.000 m^2 of newly installed capacity in 2004[22]. In 2005, 72.000 m^2 of collector area were newly installed resulting in a total installed capacity of 516.285 m^2 [23]. Italy became the second largest market in Europe, and much more stable than other emerging European markets despite the fact that had a decrease by 5% in 2009, with 400.000 m^2 of collector area of newly installed capacity. Due to its geographical location and to its high-energy dependency (86,8% in Italy compared with a European average of 53,8%), this market represented a very strong potential for solar thermal in 2009 [25]. In 2010, it continued as the second solar thermal market in Europe with 490.000 m^2 of collector area of newly installed capacity representing an increase of 3,2% [26]. The market was characterized by a difficult start due to the economic crisis and uncertainty with the legislative framework and the law No. 90 of 2013 modified the tax deductions for energy efficiency measures in buildings, increasing the deductible share to 65% of the investment costs over 10 years [29]. In 2014, the falling trend in newly installed capacity continued, with newly installed collector area down to 268.500 m^2 due to the persistent economic crisis and bottlenecks in the support schemes. The market has consequently fallen by 25%.in the meantime, 88% of the installed collectors were flat plate and 12% evacuated tubes. Moreover, 58,5% were thermosiphon systems and 41,5% forced circulation systems. In 91,5% of the cases, the installations were for sanitary hot water [30].

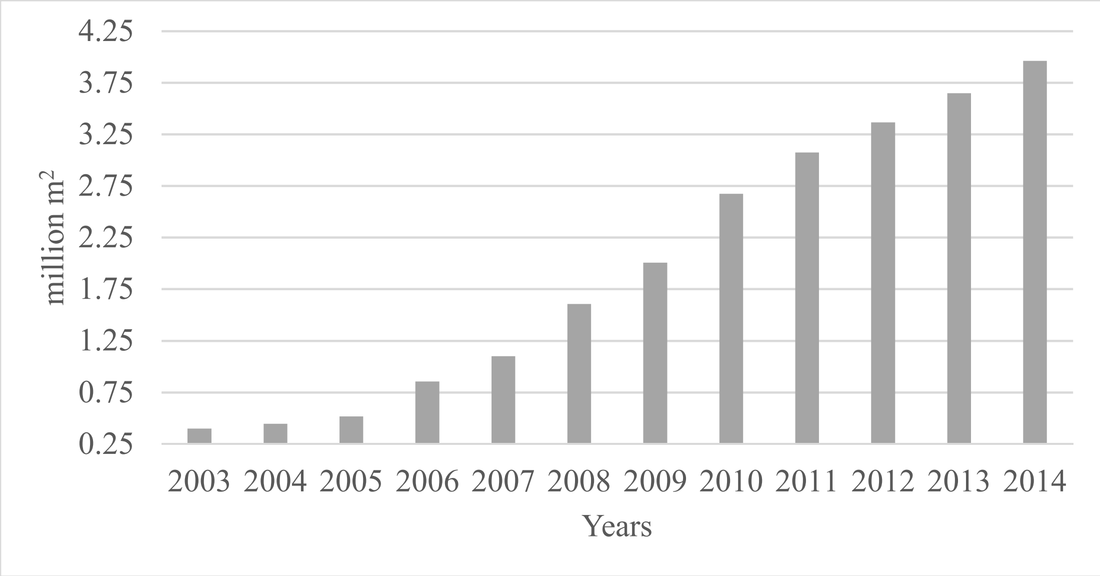

Figure 20: Total glazed area in operation in Italy

In Figure 20 it is shown that the rapid growth of the total glazed area which began in 2003 marked close to 400.000 m^2 of collector area. In 2014, it reached almost 4 million m^2 of collector area.

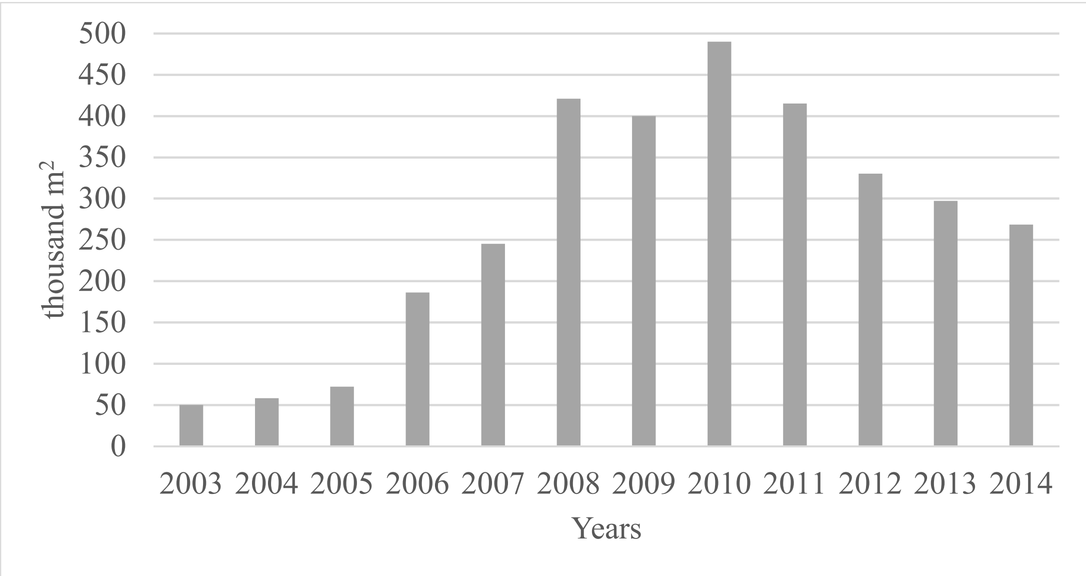

Figure 21: Total newly installed glazed area in Italy

As presented in Figure 21, the upcoming growth of newly installed capacity reached to 421.000 m^2 of collector area in 2008. In 2009, there was a small reduction and in 2010 it reached to 490.000 m^2 of collector area for a steady decline to follow and in 2014 the newly installed marked 268.500 m^2.

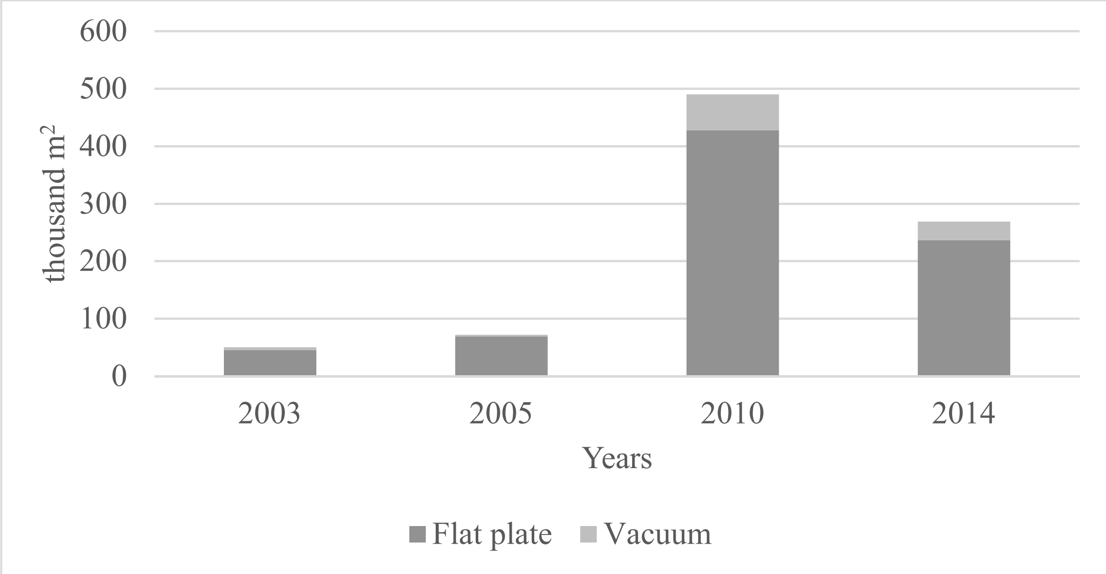

Figure 22: Flat plate and vacuum collectors in Italy

From Figure 22, it is apparent that except for 2010 and 2014 when vacuum collectors had a remarkable share of 13% and 12% respectively, the other years flat plate collectors where the dominant player.

2.4.5. SPAIN

During 2003, Spain had 50.000 m^2 of collector area of newly installed capacity while the total installed capacity in operation was 341.556 m^2 of collector area [21]. The Spanish market grew to 90.000 m^2 of newly installed solar thermal capacity representing an increase of 29% in 2004 [22]. In 2005, there was 19% growth marked by 107.000 m^2 newly installed capacity. The new national solar obligation, which came through a revision of the Technical Building Code according to which from September 2006 and onwards, almost all new buildings are required to cover 30-70% of their domestic hot water demand with solar thermal energy [23]. The Spanish market underwent a downturn of 10% in the newly installed capacity corresponding to 391.000 m^2 of collector area. The positive effect of the Spanish building code introduction has been negated by the collapse of the Spanish building sector in 2009 [25]. For the second year in a row, Spain contracted and remained at 336.800 m^2 of collector area of newly installed capacity in 2010 [26]. The newly installed capacity reached 228.721 m^2 of collector area with a small increase of 1,3%. The main reason behind the results achieved in the Spanish market in 2013 was the growth reported in Andalusia. By the end of 2013, the installed capacity totaled 2.81 million m^2 of collector area, an increase of 9% over one-year period [29]. The newly installed capacity reached 251.249 m^2 of collector area with an increase of 9,8% and the installed capacity totaled 3,05 million m^2 of collector area representing an increase of 9% [30].

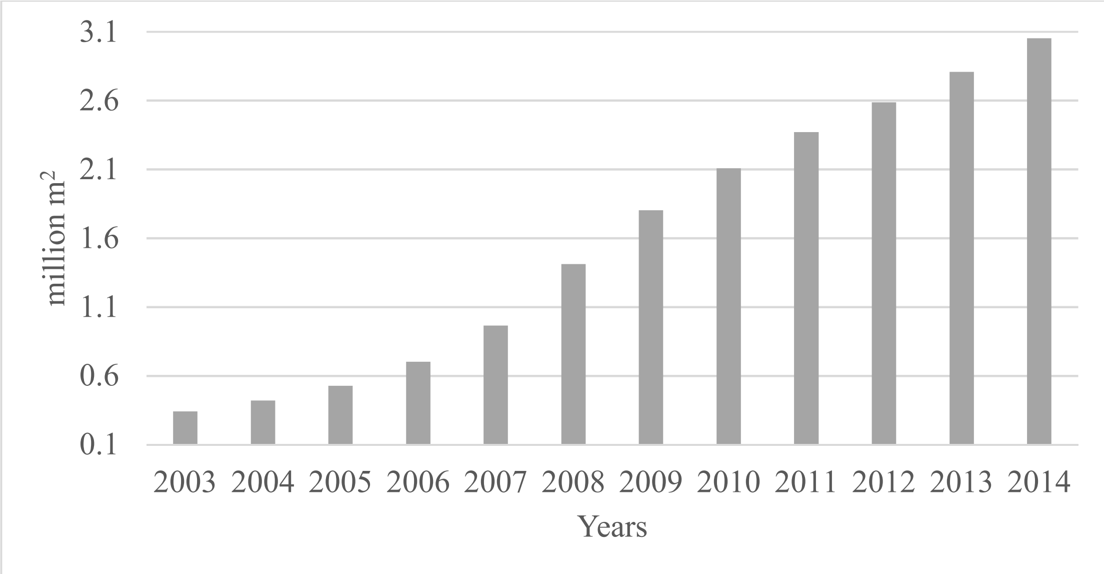

Figure 23: Total glazed area in operation in Spain

The increasing trend of the total glazed area in Spain is presented in Figure 23 which began at 341.566 m^2 in 2003and managed to reach to 3 million m ^{2}of collector area in 2014.

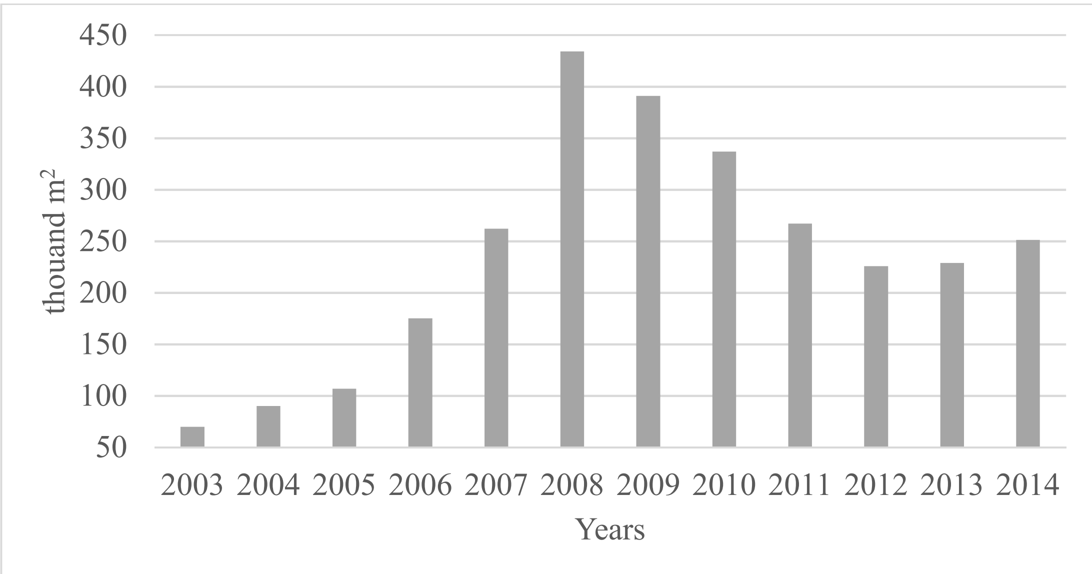

Figure 24: Total newly installed glazed area in Spain

As presented in Figure 24, the newly installed capacity reached to 434.000 m^2 of collector in 2008, followed by a decline until 2012 when it marked below 225.683 m^2 of collector area. In 2014 there was an increase that resulted in 251.249 m^2 of newly installed.

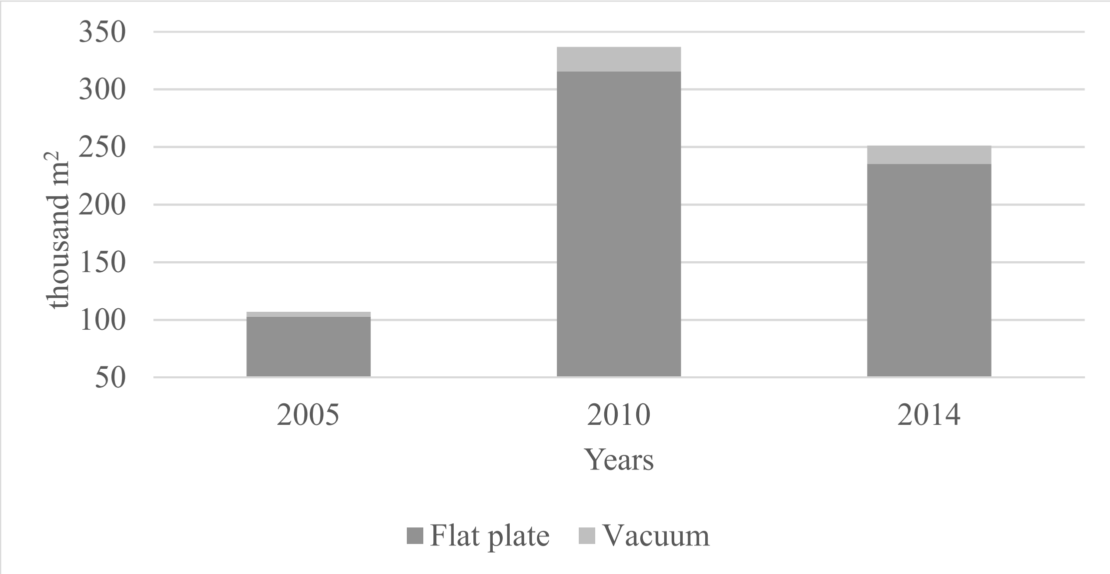

Figure 25: Flat plate and vacuum collectors in Spain

Flat plate collectors in Spain have the largest share of the market and vacuum had some small shares of 6% in 2010 and 2014 as presented in Figure 25.

2.4.6. FRANCE

In 2004, France grew to 52.000 m^2 of collector area by a considerable tax break for solar thermal systems - 40% of the hardware costs can be reclaimed with the income tax declaration [22]. The market in 2005 had a growth rate of more than 100% and increased to 122.000 m^2 of collector area of newly installed capacity [23]. In 2009, newly installed capacity in Metropolitan France decreased by 15% representing 265.000 m^2 of glazed collectors. The domestic hot water systems installations decreased by 14% and combisystems by 56% [25]. In 2010, the newly installed capacity in France was 256.000 m^2 of collector area which represented a reduction of 3,4%. The market contracted for the second year in a row [26]. The market contracted by 24% in terms of overall solar thermal collectors installed surface by 190.300 m^2. Sales of domestic solar water heaters were down 21% to 20.500 units while combi solar systems also fell by 21% to 1.100 units in 2013 [29]. In 2014, the installed area of solar thermal collectors fell by 21% to 150.500 m². Domestic solar water heaters took an 18% drop in terms of collector area (-15.000 m²). However, the number of units installed decreased less (-9%) [30].

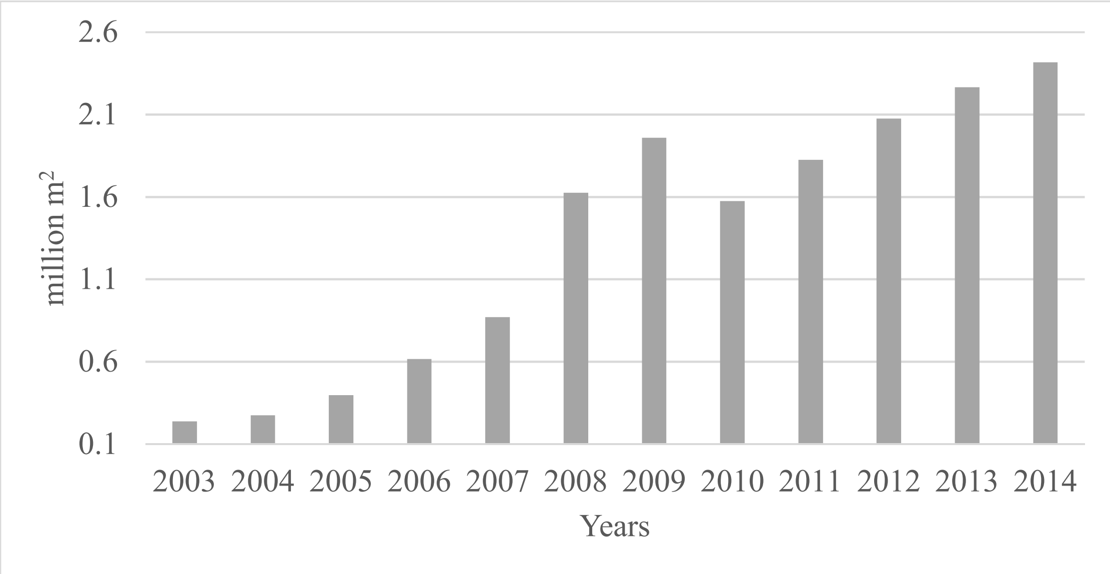

Figure 26: Total glazed area in operation in France

In Figure 26, the total glazed area in operation is presented which in 2009 reached almost 2 million m^2 of collector area. After a small decrease in 2010 marked at 1,57 million m^2 of collector area, there was a stable increase that in 2014 reached to 2,42 million $m^2$of collector area.

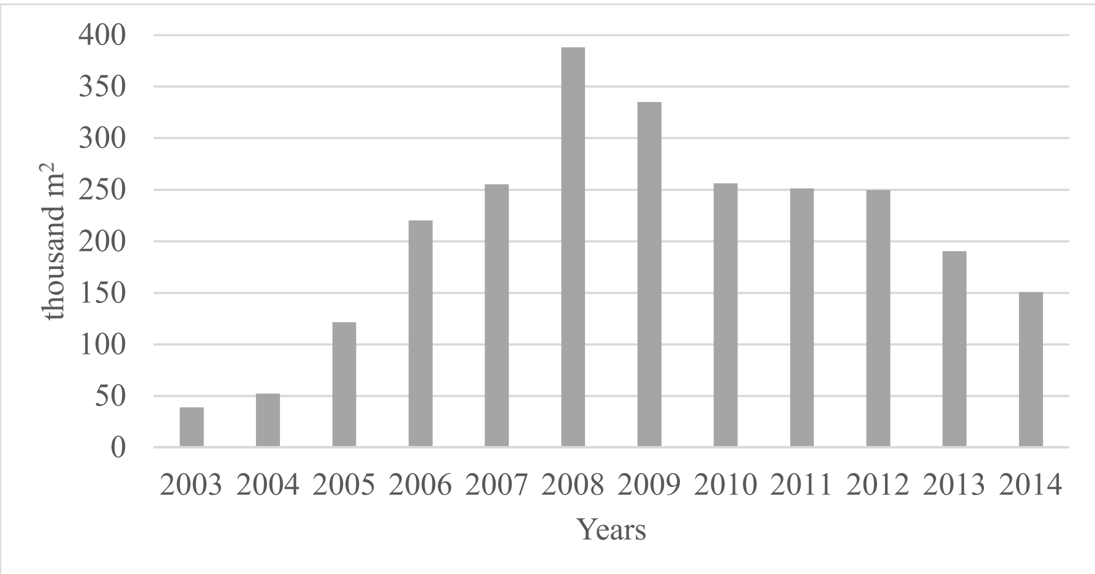

Figure 27: Total newly installed glazed area in France

As presented in Figure 27, the escalation of the total newly installed glazed area that began in 2003, ended in 2008 by reaching 388.000 m^2 of collector area. Afterwards, there was a decline for some years and in 2014 the newly installed area marked 150.500 m^2 of collector area

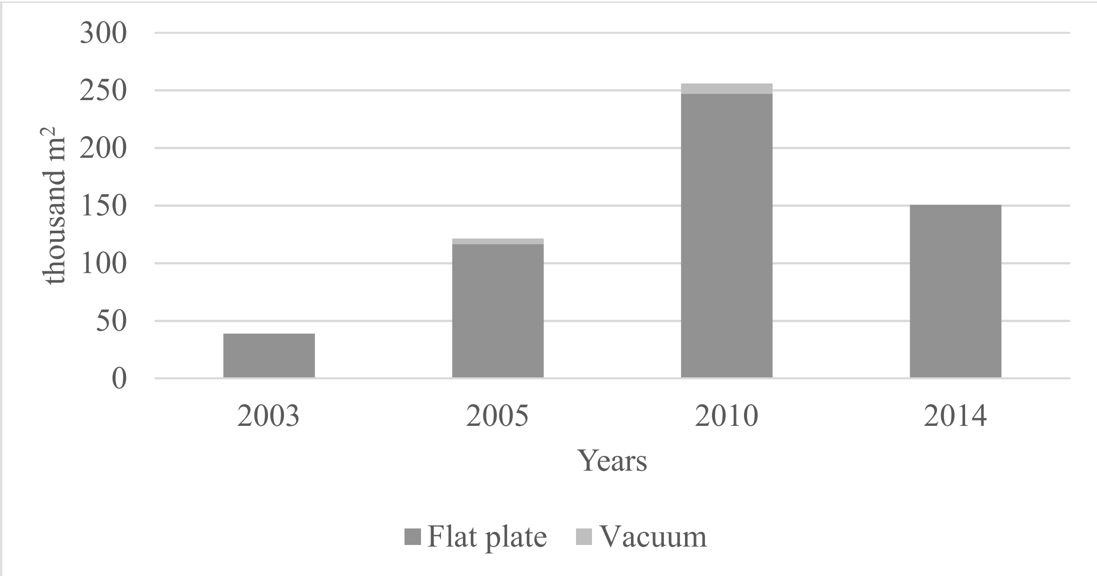

Figure 28: Flat plate and vacuum collectors in France

It is apparent in Figure 28, that the flat plate collectors played the basic role in the solar thermal market of France.

2.4.7. POLAND

In 2004, the Polish solar thermal market had 33.000 m^2 of collector area of newly installed capacity while the total installed capacity in operation was 102.520 m^2 [22]. It continued growing by 35.000 m^2 and 41.400 m^2 of collector area of newly installed capacity in 2005 and 2006 respectively [23, 24]. In 2009, the market represented 144.000 m² of collector area of newly installed capacity representing an increase of 11% [25]. Despite the absence of financial incentives, the Polish market enjoyed a steady growth over recent years. However, only a very small increase of 1,1% was reported with the newly installed capacity reaching 145.906 m² of collector area in 2010 [26]. In spite of a strong decrease of 9,2% in 2013, the Polish market totaled 274.100 m² of collector area of newly installed capacity. The total installed capacity in operation exceeded the threshold of 1,5 million m² of collector area representing an increase of 33% [29]. Sales of solar collectors in 2014 were 260.000 m^2 of collector area revealing a reduction of 5%. The total installed capacity reached 1,7 million m² of collector area [30].

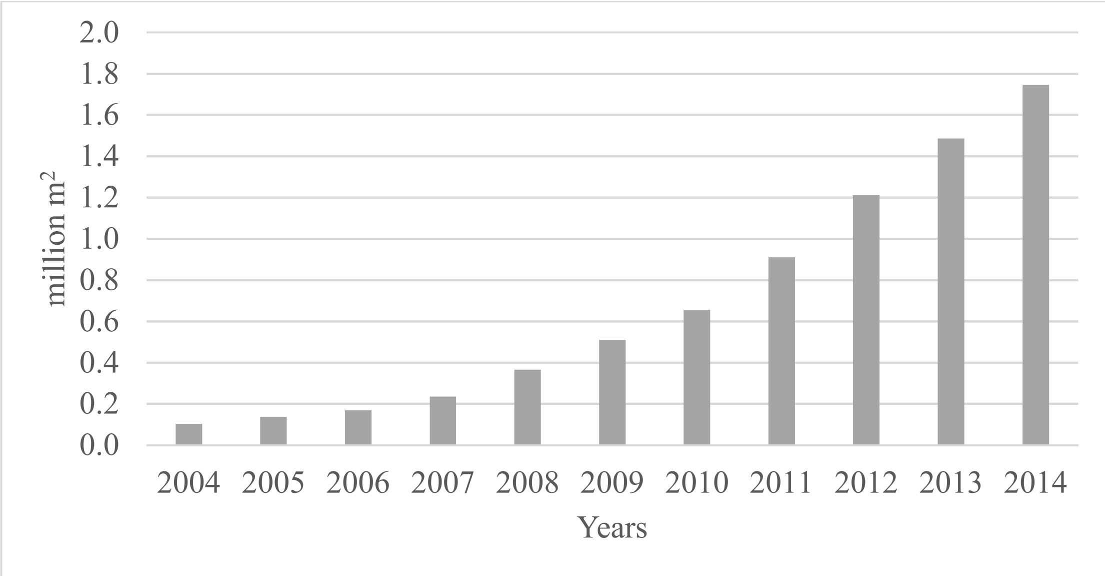

Figure 29: Total glazed area in operation in Poland

In Figure 29, the rapid growth of the total glazed area in operation in Poland is presented. It began in 2004 at 102.520 m^2 of collector area and after 10 years managed to reach almost 1,8 million m^2 of collector area in 2014.

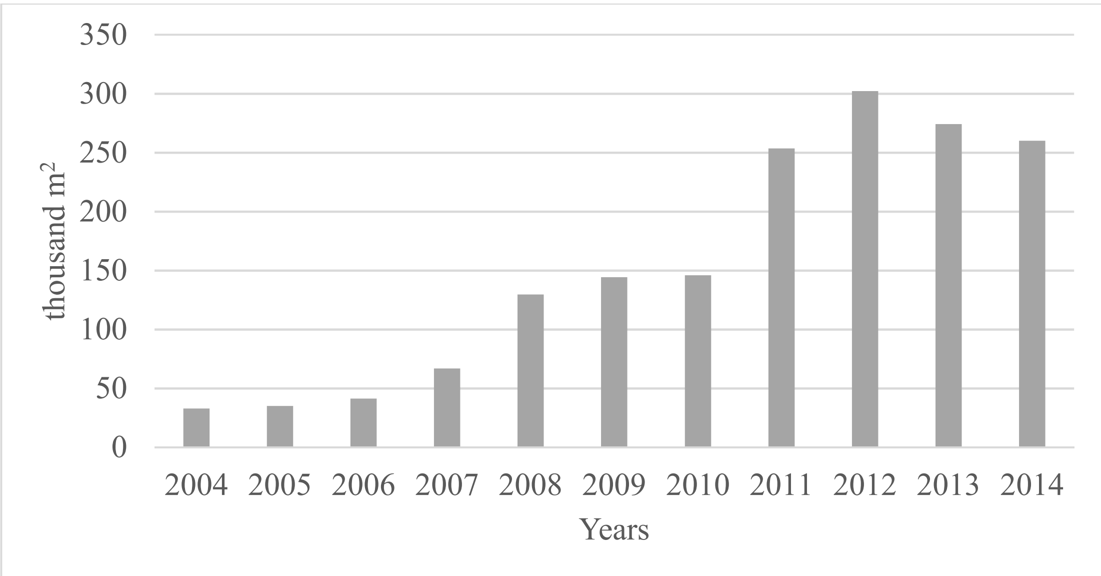

Figure 30: Total newly installed glazed area in Poland

As presented in Figure 30, the market was growing greatly and in 2012 marked 302.000 m^2 of collector area of newly installed capacity. From then onwards, there was a reduction and in 2014 the newly installed capacity was 260.100 m^2 of collector area.

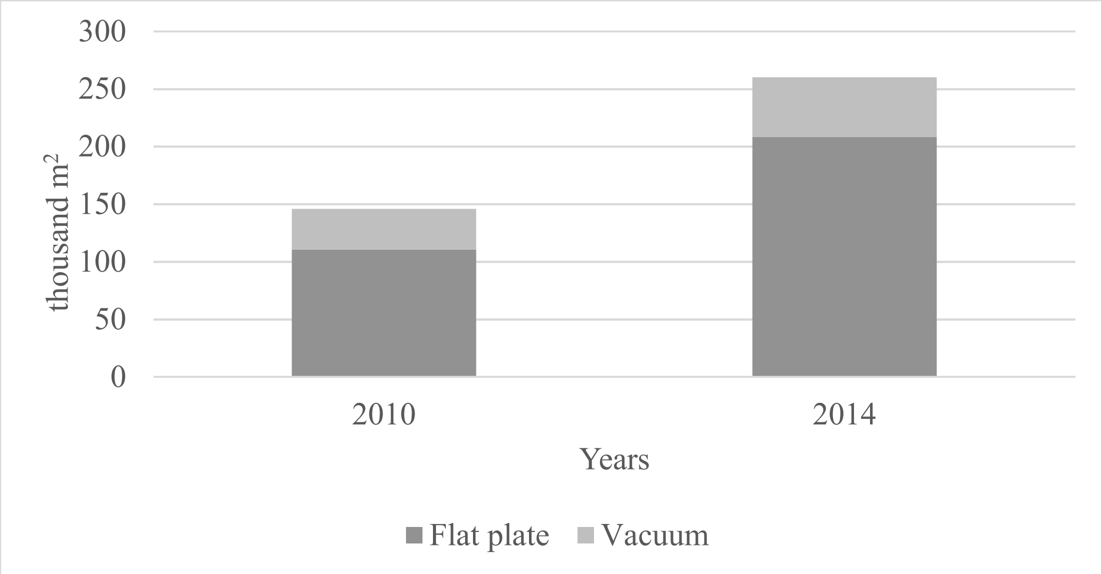

Figure 31: Flat plate and vacuum collectors in Poland

As shown in Figure 31, flat plate collectors were the dominant players in the Polish market but the vacuum ones managed to 24% and 20% share of the market in 2010 and 2014 respectively.

2.4.8. CYPRUS

In 2004, Cyprus had 30.000 m^2 of collector area of newly installed capacity and the total installed capacity was 450.200 m^2 of collector area [22]. Furthermore, there was a growth of 50.000 m^2 of collector area of newly installed while 500.200 m^2 of collector area were totally installed in operation [23]. In 2009, 735.200 m^2 of collector area were totally installed in operation [25]. There was a reduction in newly installed capacity that accounted for 30.713 m^2 of collector area during 2010 that continued to 28.437 m^2 of collector area in 2011 [26, 27]. For third year in a row, the market of Cyprus decreased by 23.917 m^2 of collector area of newly installed capacity and the total installed capacity in operation was 707.776 m^2 of collector area [28]. The dramatic decline continued also in 2013 and 2014 with 20.991 m^2 and 19.467 m^2 of collector area of installed capacity respectively [29, 30].

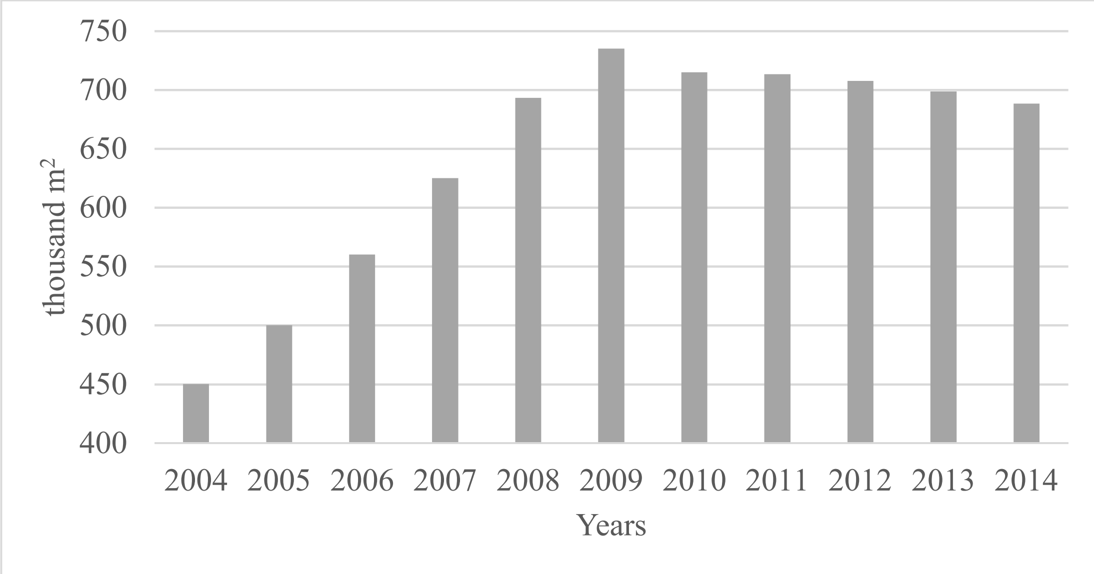

Figure 32: Total glazed area in operation in Cyprus

As presented in Figure 32, the growth of that total glazed area in operation that resulted to over 735.200 m^2 of collector area in 2009 was followed by a reduction that reached to 688.234 m^2 of collector area in 2014.

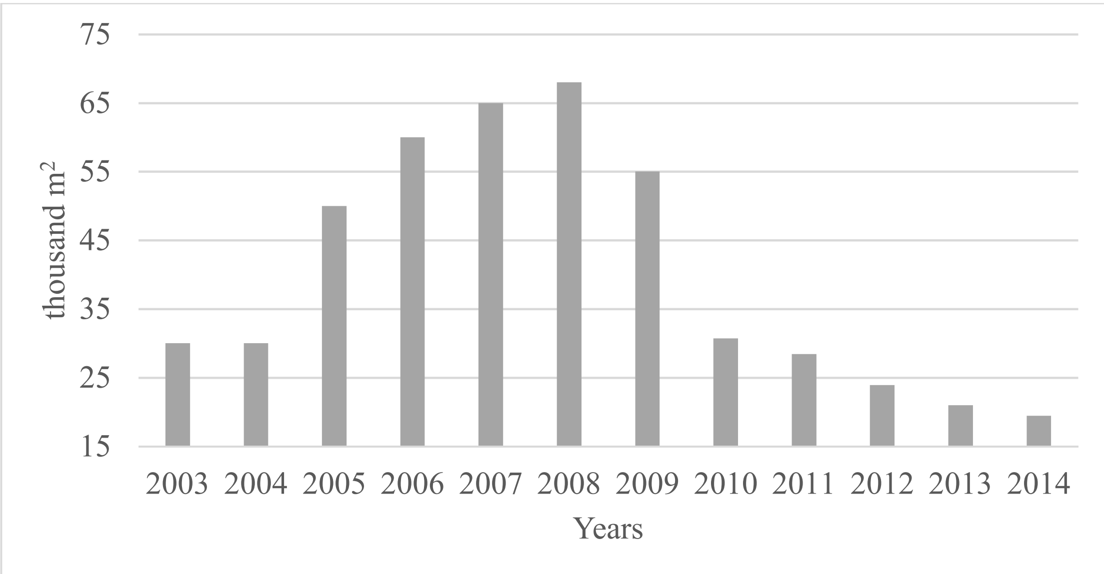

Figure 33: Total newly installed glazed area in Cyprus

From Figure 33, it is seen that the total newly installed capacity in Cyprus that marked 68.000 m^2 of collector area in 2008 was followed by a big reduction over the next years and resulted lower than 20.000 m^2 of collector area in 2014 mainly because of the economic crisis of 2008-2009.

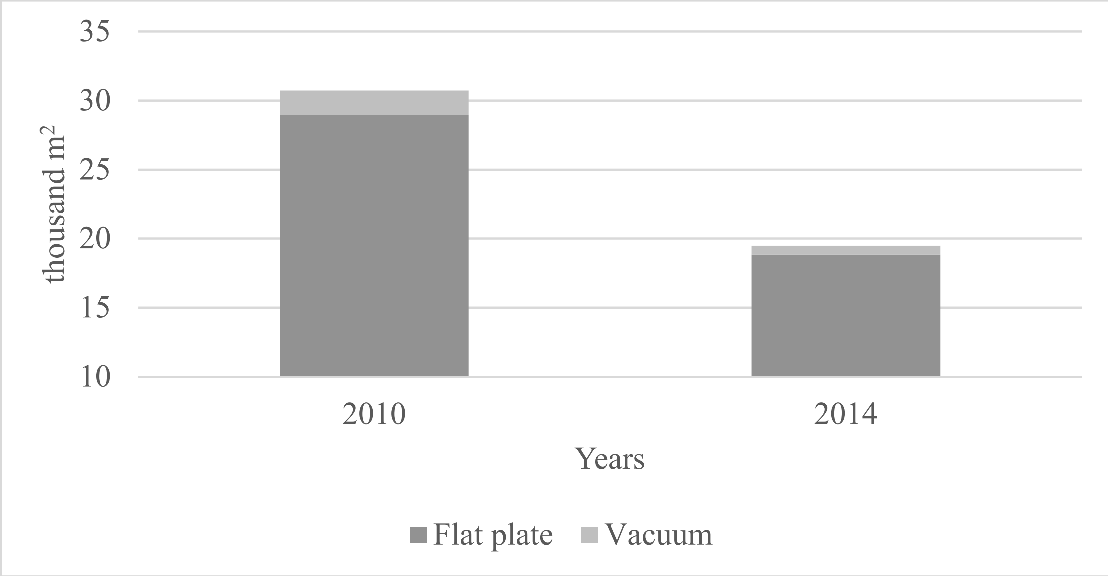

Figure 34: Flat plate and vacuum collectors in Cyprus

From Figure 34 it is apparent that the flat plate collectors had the main share of the market with vacuum collectors' share being 6%.

2.5. DOMESTIC SOLAR HOT WATER SYSTEMS

The main component of a solar water-heating system is the solar collector that absorbs solar radiation and transfers it into a heat transfer fluid which in turn transfers heat into a water storage tank [31]. Common domestic solar hot water systems consist basically from flat plate solar collectors, a storage tank with a mounding base and the necessary plumbing. Average annual system efficiency for the conversion of solar radiation to useful energy in the form of hot water varies between 30% and 40%, depending mainly on the type of solar collector used [32, 33].

Domestic solar hot water systems are a viable alternative for the replacement of electricity and fossil fuels used for water heating [32]. The types of the heating systems have two categories: active and passive. Active systems use a mechanical system to circulate the heat transfer fluid while passive systems use density gradients to circulate the heat transfer fluid. They are categorized in: 1) Combisystems and 2) Forced circulation systems. Thermosiphon systems are systems in which the storage tank and collector are physically separated and the transfer is driven by natural convection. Active and thermosiphon systems are further classified into two types: 1) Direct or open loop systems where the water in the tank is itself the heat transfer fluid and circulates through the collectors (this type is not appropriate in climates where freezing temperatures occur) and 2) Indirect or closed loop systems in which a pump circulates the heat transfer fluid through the collectors and a heat exchanger that transfers heat to the water. There are two common types of solar thermal collectors for water heating: flat plate collectors and evacuated (vacuum) tubes collectors [31].

A flat plate solar collector consists of a black absorber where the absorbed solar radiation is converted into heat that later is conducted to a fluid. The absorber includes the pipes through which the thermal fluid is flowing through. The back and sides of the absorber have insulation and on the front side there is a transparent cover that allows solar radiation to reach the absorber but reduces heat losses to the atmosphere. All of these, are packed in a metal housing that provides protection from the weather conditions and offers structural support as presented in Figure 35. Flat plate collectors are categorized according to the medium which they heat in air and liquid collectors [34].

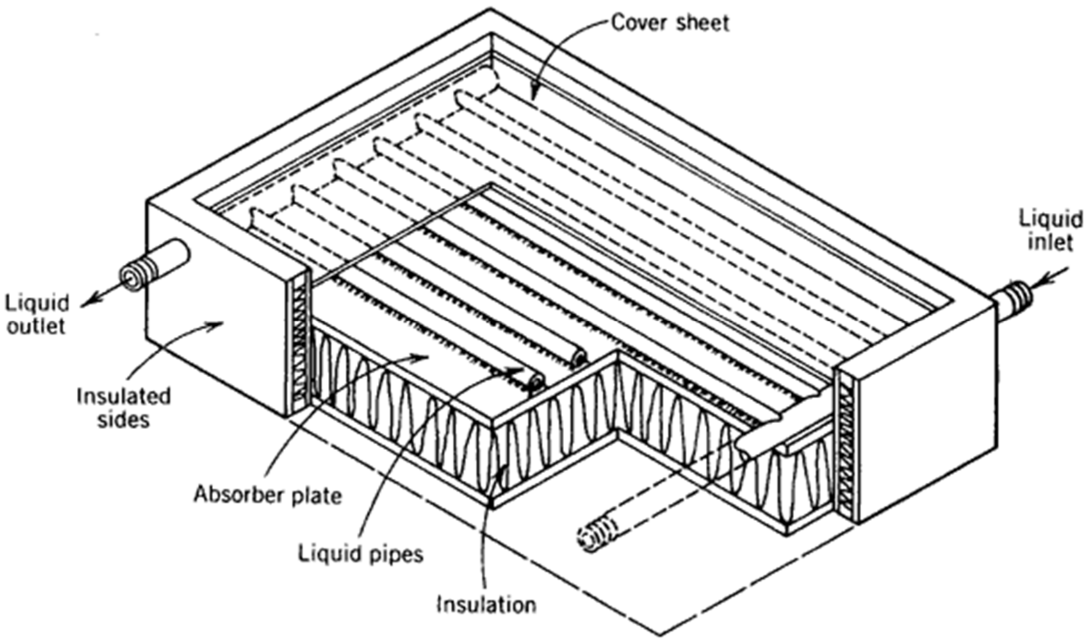

Figure 35: Flat plate collector

Usual configurations used are, flow channels corrugated on the body of the absorber area, also known as sandwich type, or pipes in contact with the absorber area, or pipes welded on fins. The sandwich configuration was mostly used during the early years, owing to its simple and low cost manufacturing [34].

Regarding the coating of the absorber, in the beginning only black powder paint was used to boost absorbance while selective paint was used by a number of manufacturers most recently. Insulation is used in order to minimize heat loses to the environment and the materials used varied from rock wool (usually 50 mm thick) in the beginning, to expanded or extruded polyurethane or combination of all of the above. Nowadays, most collectors use polyurethane due to its low thermal conductivity and its high moisture resistance. Furthermore, the cover for the absorber mainly used is low iron tempered glass (3–5 mm thickness) while some few collectors have plastic glazing, usually acrylic. Aluminum is used for the casing for the sides and a sheet of galvanized steel for the back. Moreover, hot water storage tanks are usually made of steel while a few exceptions recently used copper. The heat exchanger used to be of serpentine type but was recently substituted by the mantle type. The boiler is protected from the weather with an outside cylinder made of stainless steel or aluminum sheet. Polyurethane is placed between the boiler and the outside casing to minimize heat losses. Although the proper mounting, for proper stratification, is vertical, storage tanks are placed mostly horizontally for aesthetic purposes [34, 35].

The solar water heating systems that use flat plate collectors have a maximum operational temperature of 90–95°C. Small systems operate based on the thermosiphonic effect, while in larger systems a small electric pump may be required to circulate water through the collectors. Flat plate collectors are easy to install and maintain. The use of a solar water heating system results to a reduction in fossil fuel consumption [36]. A flat glazed solar collector is shown in Figure 36.

Figure 36: Flat glazed solar collector

The auxiliary heater is installed in the tank or at the user point depending on the different systems available in the market. The cost of solar energy collecting systems differs relying on the type of material used for the case of the collectors, the absorbent plate and the water storage tank. A typical system contains two collectors (total 4–6 m^2 surface area) and a 160–200 l capacity water storage tank. This kind of system costs approximately 1.300€, which is accounted for by the installer's overheads and marketing costs [36].

Figure 37: Evacuated tube solar collector

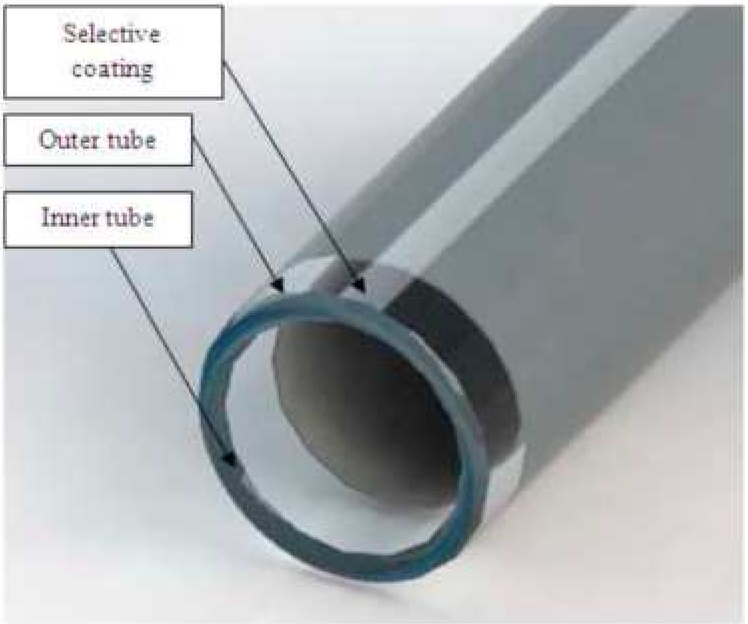

Figure 38: Evacuated tube [37]

Another type of solar collector used in this type of systems is the evacuated tube solar collector as presented in Figure 37. It consists of parallel evacuated glass pipes where each evacuated pipe consists of two tubes, one is inner and the other is outer tube as shown in Figure 38.

2.6. DOMESTIC SOLAR HOT WATER SYSTEMS USE IN DIFFERENT EU COUNTRIES

In a relevant study for domestic solar hot water systems, Shariah in 2002 used the annual solar fraction of the system as an indicator to find the optimum inclination angles for a thermosiphon solar water heater installed in northern and southern parts of Jordan. TRNSYS was used for calculations. The area of the collector was varied between 2 and 5 m^2 and the storage tank was modelled as a fully stratified tank with a variable number of nodes or segments. Some of the conclusions of the study were:

a) The optimum tilt angle for the maximum solar fraction was larger than any of those for the maximum solar radiation at the top of the collector by about 5 to 8°,
b) The optimum tilt angle of the collector was depended on the operation strategy,

c) Systems operating with sufficiently high solar fraction had a range of optimum angles from φ to φ+20°,

d) The useful energy collected by the system was larger than the load energy during summer especially for a collector with an area of 3 m^2 or larger [41].

In another study, Kalogirou in 2004 showed that by using solar energy, large amounts of greenhouse polluting gasses could be avoided and the environmental protection by the two most widely used renewable energy systems: solar water heating and solar space heating. Two types of solar systems were considered in this study; a solar water heating system and a solar space and water heating system. In both systems flat plate collectors were used. All systems were simulated with the Polysun program with the weather conditions of Nicosia, Cyprus and the monthly solar radiation and mean ambient air temperature for Nicosia were derived from the typical meteorological year. Three types of solar water heating systems were considered, one with electric heating backup, one with a combination of electricity and boiler backup and one with only a boiler backup. Finally, the results showed that by using solar energy, considerable amounts of greenhouse polluting gasses are saved. Regarding the domestic hater heating systems with electricity or diesel backup, the saving, compared to a conventional system, was about 80%, whereas for the case that both electricity and diesel backup were used, it was about 75%. As for the solar space heating and hot water system, the saving was about 40% [42].

Moreover, in 2004 Mills used Geographical Information Systems (GIS) in compliance with existing solar hot water performance evaluation tools in order to produce models with better spatial resolution than those used before in Australia. The authors concluded that GIS can be used to generate much more detailed assessments of SHW system performance in conjunction with an existing evaluation tool such as TRNSYS which was the one that was used for the simulations [38].

Furthermore, Rogers in 2013 examined the possible way of using suitably sized solar water heating systems with heat storage to supply all the hot water demand throughout the summer period in northern cloudy climates like allowing the alternative heating system to be turned off for the season. A house experiencing the climatic conditions of St. Petersburg with south facing solar panels mounted at a tilt angle of 37° and variable sized thermal stores was created. The area of the solar collector was increased until the maximum temperature at any hour of the water in the store reached 90 ˚C. The following parameters were calculated:

a) The efficiency of the solar collector based on the ambient air temperature with the fluid exit temperature assumed to be equal to the store temperature from the previous hour plus 10 ˚C,
b) The energy collected by the collector based on its efficiency and the calculated irradiance for that hour,
c) The amount of net energy stored when the additional energy from the panel and store losses have been accounted for.

It was shown that a suitably sized system can provide the amount of the domestic hot water demand during the summer period with only a minimum use of auxiliary water heating. During summer the inclination of a solar panel was not found to be critical and horizontal panels could also be used in situations where a south facing roof is not available. Furthermore, there were locations that a vertically mounted solar panel would provide the highest solar fraction but a disproportionate increase in panel area was needed so to achieve this [39].

There is a research of Nhut in 2013 that was conducted in order to determine optimal control variables of a collector pump placed on a collector loop to improve the performance of a solar domestic hot water system. A mathematical model of the system was developed to predict its operating performance under real weather conditions at Jeju Island, South Korea. The control variables of the collector loop were examined and the effects of many parameters like solar collector area, initial water temperature, and volume of storage tank were investigated. The main parts were solar collectors, a water storage tank, a boiler, panels for heating, and a computer for data recovery. The vacuum tube collector had a total collection surface area of 26 m^2 and eight collector arrays were connected in parallel. The material of the panel of the solar collector was aluminium and the panel was installed with a 45° tilt angle. The thermal storage tank had 1200 l capacity and was constructed of stainless steel with polyurethane insulation. A model in Matlab was developed to simulate optimal performance of the collector loop. The simulation assumptions were that the initial value of the inlet temperature collector is equal to the ambient temperature, the initial value of the water temperature in the storage tank is 30°C and that the initial value of the mass flow rate is 0.05 kg/s. Some of the conclusions of the study were:

a) The optimal equation of the variable mass flow rate $m_v = 0.05\ \Delta T\ A_c /60$ (kg/s), resulting from the simulation, is recommended for use in the collector loop to improve the system performance,
b) The useful heat gain of the collector during the day with the proposed variable mass flow rate control logic is only 1.54% higher than that of the constant mass flow method,
c) When the initial water temperature of the storage tank varies from 22 °C to 55 °C, the useful heat gains and the electricity consumption of the collector pump decreased while the heat loss of the storage tank and the heat flux transferred to the user were increased and
d) While the solar collector area induces useful and rapid heat gain increases, the ratio of the total useful heat gain per unit collector area for one day will be decreased [45].

In another study of 2015, Tsalikis examined the solar thermal utilization in typical residential buildings in order to identify the impact towards NZEB. A feasibility analysis was performed for a number of different sized solar combi and photovoltaic systems. The analysis was conducted for each of the four climatic zones designated in KENAK, which is the regulation describing the methodology of calculating the energy performance of buildings in Greece, in order to identify the solar potential from photovoltaic and solar thermal utilization in typical residential buildings towards nearly NZEB. Regarding the energy calculation of the proposed solar thermal systems, the F-chart method was used; while for the heating and cooling loads of the buildings an EN 13790 (EN 13790, 2008) methodology based software (TEE-KENAK) was implemented. The RETSCREEN software (International, 2014) was used in order to calculate the electricity produced from the different photovoltaic systems examined. The authors concluded that the implementation of a solar combisystem for space and water heating, together with a small photovoltaic system could provide the amount of energy for a building to be considered as a nearly NZEB. In the cases that were examined, the solar energy systems were able to cover more than 76% of the total primary energy demand and in some cases up to 97%, while presenting a depreciated payback period of less than 6 years [40].

In Duomarco's study of 2015, an extension of standard ISO 9459-2 was developed with the goal of establishing a new way of classifying solar domestic hot water systems. In this software the daily solar domestic hot water system operation is modelled with a heat-limited consumption scheme, fixed by a nominal temperature, T_{dn}, and a daily nominal hot water volume production V_{dn}. The method is based in the ISO 9459-2 standard's experimental procedures and a new long-term-performance-prediction calculation with a different load pattern. The items calculated by the software are: the discarded energy due to overheating, the remaining energies in store, after evening draw-off and in the next morning, the energy loss through store surface, the useful energy in hot water extraction and the auxiliary energy necessary to reach nominal settings [44].

There is another study of Abd ur Rehman in 2016, in which the evaluation of the optimum selection criteria for domestic solar water heating systems based on the techno-economic aspects of evacuated tube and glazed flat plat solar collectors was examined. Ten different cities in the Kingdom of Saudi Arabia that represented different geographical locations and received different amounts of solar radiation were selected for the study. Climatic data such as latitude, longitude, location, elevation, and heating and cooling design temperatures recorded by NASA was used in the simulation. RETSCREEN software was used to calculate the monthly and annual solar radiation on the tilted surface in order to understand the effect of slope adjustment on the amount of solar radiation received by the solar collector. The simulations were performed for a typical house with six people paying the complete cost of the system without any incentives and then the effect of varying the number of occupants was examined. Some of the conclusions of the article were:

a) Credibility of evacuated solar water heating collectors was justified in terms of a higher solar fraction, higher energy savings, and GHG emissions reduction potential,
b) Some cities (Nejran and Bisha) experienced higher values of daily solar radiation that made them an attractive option for SWH applications,
c) Fuel savings and GHG emissions reduction by adopting solar water heating technology showed its economic and eco-environmental benefits,
d) The result of increasing the number of occupants was the decrease of the payback period and the increase of the benefit to cost ratio [43].

3. METHODOLOGY

3.1. APPLYING SYSTEM ADVISOR MODEL

The aim of this study is to examine the solar coverage of domestic solar hot water systems for typical residential buildings across EU. For this reason, a number of households throughout EU are going to be investigated, taking into account their total geographical area, their climatic conditions and their total installed collector area. System Advisor Model is going to be used in order to make the calculations, find the optimum angle for the collectors according to the countries' latitude and to estimate the energy savings and emissions reduction that can result from the domestic solar hot water systems usage for each country taken into account.

3.2. SYSTEM ADVISOR MODEL (SAM)

System Advisor Model or SAM is developed by the National Renewable Energy Laboratory (NREL) of the U.S. Department of Energy. It is a model that estimates performance and financial metrics of renewable energy systems. It can be used by project developers, policymakers, equipment manufacturers, and researchers in order to evaluate financial, technology, and incentive options for renewable energy projects. SAM runs simulations on the performance of photovoltaic, concentrating solar power, solar water heating, wind, geothermal, biomass, and conventional power systems. Furthermore, it can make performance predictions and cost of energy estimates for grid-connected power projects based on installation and operating costs and system design parameters that should be specified as inputs to the model [46].

SAM consists of a user interface, calculation engine, and programming interface There are 3 basic functions that the user interface executes:

a) It provides access to input variables, which are organized into input pages where the input variables describe the physical characteristics of a system, and the cost and financial assumptions for a project.
b) It allows to have the control of how SAM runs simulations. It can run a basic simulation or advanced simulations for optimization and sensitivity studies.

c) It provides access to output variables in tables and graphs on the Results page, and in files that can be opened in a spreadsheet application or other software [46].

SAM includes libraries of performance data and coefficients that describe the characteristics of system components such as photovoltaic modules and inverters, parabolic trough receivers and solar collectors, wind turbines, and bio power combustion systems. Its performance models make hour-by-hour calculations of a power system's electric output, generating a set of 8.760 hourly values that represent the system's electricity production over a single yea [46].

SAM includes performance models for a lot of technologies such as photovoltaic (PV) systems (flat-plate and concentrating photovoltaic), conventional thermal (a simple heat rate model), solar water heating for residential or commercial buildings, large and small wind power, geothermal power and geothermal co-production and biomass power. There are also financial models included for different kind of projects like residential (retail electricity rates), commercial (retail rates or power purchase agreement) and utility-scale (power purchase agreement) [46].

There are several case studies that SAM has been used. In a report of 2011, an analysis of solar water heating break-even costs was conducted for residential customers in the United States and the evaluation of some of the key drivers on a regional basis. SAM was used for all the necessary calculations and estimations The first part had to do with residential solar water heating for both an electric and natural gas auxiliary water heater and included a single set of assumptions for financing, system performance, hot water usage, and several other factors. The primary target of this paper was on households with electric water heating and the authors examined systems with electric backup in more detail because of the economics of these systems that were are better than those for households using natural gas due to the difference in fuel prices. They also investigated the sensitivity of the break-even cost to five major drivers: system performance, hot water usage, financing parameters, fuel prices, and policies. The authors concluded that the break-even price varied by more than a factor of five even though the amount of energy produced varied by less than a factor of two. This difference was driven by incentives but even without incentives, large variations in break-even cost would remain given the range of hot water usage and solar energy available. Another conclusion was that solar water heating systems which replaced conventional electric systems were more likely to achieve break-even costs than solar water heating systems replacing conventional natural gas systems [55].

The NREL PV Validation of 2012 included case studies that compared PV measured performance data with simulated performance data using appropriate weather data. The measured data sets were taken from NREL onsite PV systems and weather monitoring stations. Four PV systems were modelled by making generally minor changes to the SAM default values [50].

Furthermore, the NREL PV Validation 2013 focused on the validation of SAM with measured performance data. There were nine PV systems analysed, for which NREL could obtain measured performance, in order to quantify SAM's ability to predict performance for these systems. These systems included three utility-scale systems (greater than 10 MW) and six commercial-scale systems (75–700 kW). All systems were modelled using onsite measured irradiance and meteorological data as inputs. The predicted alternating current (AC) power production of SAM was compared to the measured AC power production for each system [49].

Moreover, in another report of 2014, SAM's modelled energy is compared to measured energy from 100 real world systems from the Locus platform. Several parameters like diversity of geography, size, age, and configurations of systems were used for this sample. The analysis was conducted over a one-year period and error metrics were calculated on time granularities of hourly, daily, monthly, and annually. The main reasons for differences between modelled and measured energy were uncertainty in irradiance and meteorological data, misspecification of losses and SAM modelling error [48].

In a comparative analysis of 2014 that was performed on nine photovoltaic systems for which NREL could acquire performance data and specifications, including three utility scale systems and six commercial scale systems, PV performance modelling tools were used for these systems and the error of each tool was analysed compared to quality-controlled measured performance data. By using SAM, the module model and irradiance input choices could change the annual error with respect to measured data by as much as 6.6% for these nine systems and a seasonal variation in monthly error is shown for all tools. Finally, the effects of irradiance data uncertainty and the use of default loss assumptions on annual error were examined together with two approaches to reduce the error included in photovoltaic modelling [47].

In addition, in a research of 2016 about solar power tower systems, Collado mentioned the importance of selecting the optimum location of heliostats, the tower height and receiver size. Regarding the figure of merit of the main optimisation which is the levelized cost of electric energy, SAM was used for the capital cost models needed for the calculation [51]. Also, Feldman in 2016 investigated the impact of changes to key PV module and system parameters on the levelized cost of energy. Module manufacturing cost, efficiency, degradation rate, and service lifetime were included in the parameters. SAM was used in order to calculate the lifecycle cost per kWh for residential, commercial, and utility scale PV systems within US [52].

3.3. TYPICAL RESIDENTIAL SYSTEMS FOR DOMESTIC HOT WATER USAGE

Thermosiphon, or natural circulation, solar water heating systems (also called passive systems) are the simplest and most used solar energy collection and utilization devices. They are intended to supply hot water for domestic use based on natural circulation or thermosiphon principle. They supply hot water at a temperature of about 60°C and consist of a collector, storage tank, and connecting pipes as shown in Figure 39 [33].

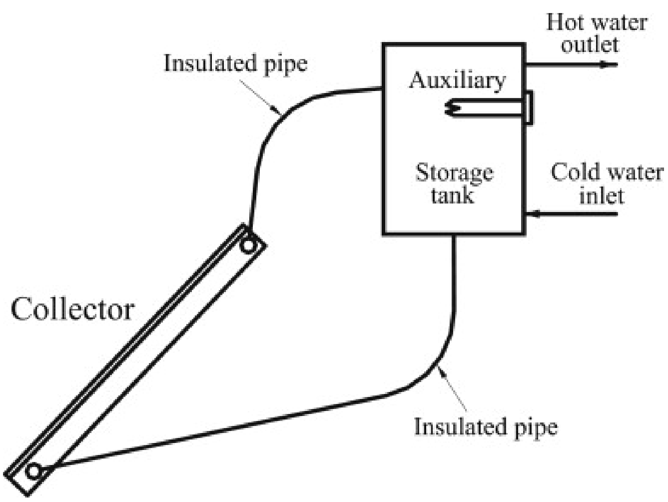

Figure 39: A schematic diagram of a thermosiphon solar water heater [54]

They heat water or a heat transfer fluid and use natural convection to transport it from the collector to the storage tank. This type of technology is applied in countries with good solar energy potential. The performance of such a system depends on many factors including the collector construction and the arrangement of the system with respect to the distance between the top of the solar collector and the bottom of the storage tank and the solar collector slope, which affects both the energy collected and the hydrostatic pressure of the system [54].

In the storage tank, hot water accumulates near the top when water is heated during the day by solar radiation. The storage tanks are sized to hold at least two days' supply of hot water in order to include periods of low solar radiation. The connecting lines should be well insulated to prevent heat losses and sloped to prevent formation of air pockets which would stop circulation [33].

The advantages of thermosiphon systems are that they do not rely on pumps and controllers, they are more reliable and they have a longer life than forced circulation systems [54]. Moreover, they do not require an electrical supply to operate and they modulate naturally the circulation flow rate Their disadvantage is that because the storage tank should be above the collector they are comparatively tall units, which makes them not very aesthetically attractive. Another disadvantage of the system is related to the quality of the water used. As the system is open, extremely hard or acidic water can cause scale deposits that clog or corrode the absorber fluid passages. There are two types of thermosiphon systems; pressurized and unpressurized. In pressurized thermosiphon units, the make-up water is from city mains or pressure units and the collectors and storage tanks must be able to withstand the working pressure. When city water is used directly, pressure reducing and relief valves must be installed to protect the system because the pressure can be greater than the working pressure of the collectors and storage tank [54].

The storage tank is well insulated to reduce thermal loses to the environment and is equipped with heat exchangers so as to heat the water with auxiliary energy. The auxiliary can be either electricity or diesel. In case the temperature of the water in the storage tank is more than the desired temperature this is mixed with the make-up water to obtain the required temperature. Typical hot water systems comprise a hot water cylinder powered either by electricity or by diesel oil through the central heating boiler [33].

The size of a thermosiphon solar system depends on the prevailing weather conditions and the hot water requirements. The collector area is determined by the daily hot water demand, which varies from place to place depending on local customs and lifestyles [33].

A typical residential thermosiphon solar system for a four-person family covers about 80% of the hot water requirements. The flat-plate collector is fixed permanently in position, and the tilt of the collector is determined by taking into consideration the predominant season of hot water use. For year-round use, the collector tilt is kept equal to the latitude of the location plus 5°. The daily overall system efficiency of a domestic solar hot water system is about 30–40%, and the temperature difference between the collector outlet and inlet is about 10°C [33].

The performance of such a system depends on many factors including the collector construction and the arrangement of the system with respect to the distance between the top of the solar collector and the bottom of the storage tank and the solar collector slope, which affects both the energy collected and the hydrostatic pressure of the system. The collector construction concerns mainly the diameter of the riser and header pipes, which determines according to the flow created by the thermosiphonic effect, the friction that needs to be overcome. The riser pipe diameter affects also the collector efficiency factor and the heat removal factor [54].

In Aye's study of 2002 there was an estimation for a thermosiphon solar water heating system for a typical Australian household, with a total collector area of 6 m^2, total water consumption of 270 l/hh/day and the hot water tank capacity of 270 l [56].

Household size determines to a large extent the required collector's area and storage tanks' volume of the solar system as stated in Martinopoulos's 2010 study and according to the Greek technical guide and EU's regulation which is shown in Table 1 [34].

Table 1: Representative domestic solar hot water size for each household size [34]

Household size	**System size**			
Persons	2 m^2/180 l	4 m^2/200 l	4 m^2/240 l	6 m^2/240 l
2	●			
3		●		
4			●	
5				●

As presented in Table 1, the collector's area and the storage tank volume may vary depending on the household size and the number of residents.

In Tsalikis's study of 2014, a four-person household in a 88m^2 detached house was used studied and nine different sized systems were considered in order to investigate the influence of the solar collector area and the storage tank volume of the solar heating system for four climatic zones. All of them consisted of glazed flat-plate collectors and the collectors' area used were 8 ,10, 12 m^2 with storage capacity of 500, 600 and 650 l respectively while the hot water demand was calculated for the whole year for a volume of 50 l/day, person at a temperature of 45 °C [53].

In a study of 2014, Vieira mentioned that the typical solar system model for Brisbane of Australia was defined as a 300 l hot water tank with an electric booster of 1.800 W and two solar collectors with copper risers and a black polyester powder-coated aluminium absorber with gross area of 1,983 m^2/ collector. The orientation was north facing and the tilt angle equal to the local latitude, 27.2° in Brisbane [57].

Greening mentioned in his study of 2014 that for the average family home in UK, the collectors used had an area of 4 m^2, they were roof-mounted at an inclination of 30° and the hot storage tank had a capacity of 250 l [58].

In 2014, Kalogirou mentioned in his study that a typical thermosiphon system in Cyprus, used 3 m^2 of collectors, 160 l of storage tank and the inclination of the collectors was at 45° from horizontal [54].

A four-person household in a 120 m^2 detached house was used as a case study in 2015. In order to meet the building's thermal load the building was equipped with a typical solar combi system, coupled with a back-up fossil fuel heater and the solar combi system consisted of an array of flat plate selective collectors and a hot water storage tank with an auxiliary boiler. Forty different combinations of solar collector array and storage tank size systems were examined so as to analyse the impact of the solar collector area and storage tank volume of the solar combi system. The sizes of the collector area were 12, 14,16, 18, 20, 22, 24, 26 m^2 and the storage capacity sizes were 750, 1000, 1250, 1500 and 2000 l [40].

Regarding the domestic solar hot water systems, it is apparent that the area of the solar collectors, the inclination, the solar access of the residential building and the climatic conditions play the most important role. The number of residents is also crucial in order to decide the optimum storage tank to cover their hot water requirements. For all these reasons, this study is going to examine all these factors by using SAM for the calculations and estimations in order to investigate the optimum solar fraction, the potential energy savings and emissions reduction for typical residential buildings across EU countries.

4. ENERGY SAVINGS FROM THE USE OF DOMESTIC SOLAR HOT WATER SYSTEMS IN EU

This chapter describes the methodology to calculate the potential energy savings and the emissions reduction for typical residential buildings over the last 10 years from the use of domestic solar hot water systems in EU countries. By taking into consideration the total installed glazed area of each country over the last years and having calculated the energy produced from a typical domestic solar hot water system, there is an estimation of the energy saved. Also, the emission factors of produced electricity are considered along with the amount of energy produced by the domestic solar hot water systems so as to provide a rough calculation for the quantity of the GHG emissions that can be salvaged. In order to evaluate the relative performance of domestic solar hot water systems compared to typical fossil fuel systems a number of factors need examination and calculations to be made. In this analysis, the outputs that were chosen to be examined are total system energy, solar fraction, net present value and payback period. System energy is the total energy produced by the system while solar fraction is the ratio of the total solar energy produced by the domestic solar hot water system to the total energy required for the residential building. Furthermore, the net present value is a measure of a project's economic feasibility that includes both revenue or savings for projects and cost. A positive net present value indicates an economically feasible project, while a negative net present value indicates an economically infeasible project. Finally, the payback period is the time in years that it takes for project savings to equal net capital cost. The domestic solar hot water system that is going to be simulated for all households in all locations across EU consists of a number of flat plate glazed collectors and a hot water storage tank while its technical and economical characteristics are shown in Table 2.

Table 2: Technical and economical characteristics of the domestic solar hot water system simulated in SAM

Characteristics of the system	Value
Type of collector	Glazed flat plate
Working fluid	Mixture with glycol & water
Number of occupants	4
Collector area	2 m^2
Number of collectors	2
$F_R(\tau\alpha)$	0,76
F_RU_L	4,5 W/m^2 C
Tilt	latitude ± 15°
Azimuth	180°
Collector cost	250€/unit
Storage cost	2.500 €/m^3
Installation cost	100€
Total cost	1.100€
Analysis period	25 years

The technical characteristics presented in Table 2 are typical values for a domestic solar hot water system representative of the technology available throughout the EU [40, 78]. $F_R(\tau\alpha)$ denotes the collector's maximum efficiency and F_RU_L denotes the collector's heat losses [59]. The inclination of the collector is set within the recommendation of the literature for each case [41]. The prices used for the economical comparison are average market prices of the EU for these kind of systems. Typical meteorological years (TMY) are used for all locations as the simulation is run with SAM which uses the TRNSYS engine.

After the simulation for the base case scenario, a number of parametric simulations are made so as to examine the influence from the number of collectors, the solar tank volume, the inclination and the number of occupants for all the locations considered across the EU. The tables of the parametric simulations can be found in Appendix.

4.1. GERMANY

The locations examined for Germany are the metropolitan areas of Hamburg in Northern Germany, the capital Berlin in Western Germany, Dusseldorf in Eastern Germany and Munich in Southern Germany in order to cover all the different climatic conditions and for which full meteorological data in TMY format were available.

Table 3: Coordinates and elevation of locations

Location	Latitude	Longitude	Elevation
Hamburg	53,63°	10°	16 m
Berlin	52,47°	13,4°	49 m
Dusseldorf	51,28°	6,78°	44 m
Munich	48,13°	11,7°	529 m

The latitude, longitude and elevation of each location are presented in Table 3. The total electricity rate for Germany, incorporating all taxes and energy prices, is 0,295 €/kWh [60]. The inclination is set at 50° and the inflation rate is set at 1%/year [40, 72]. The average daily hot water usage is 50 kg/day/person and the solar tank has a volume of 0,2 m^3.

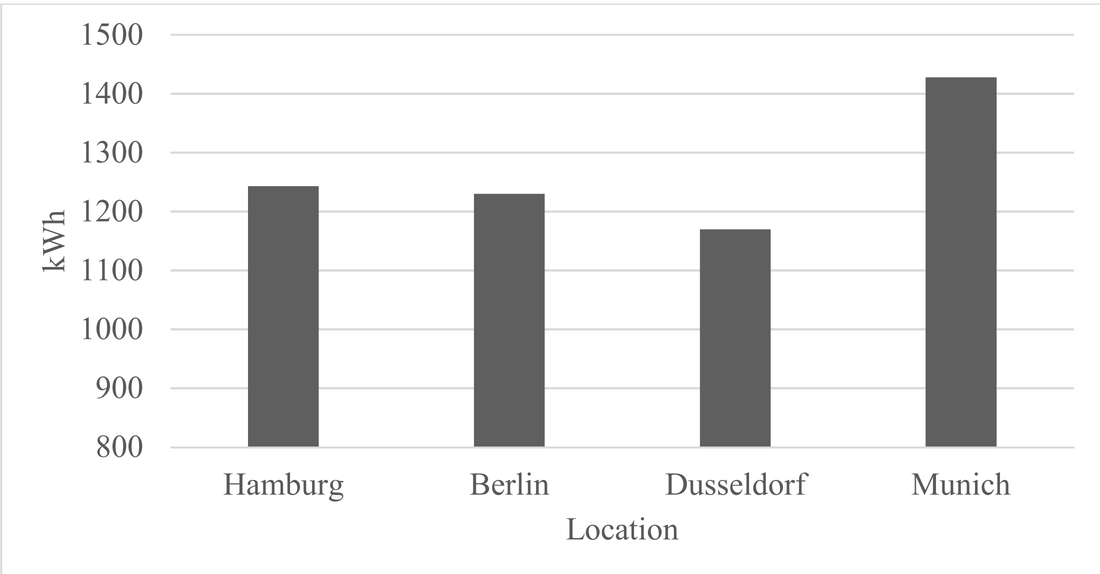

Figure 40: System energy

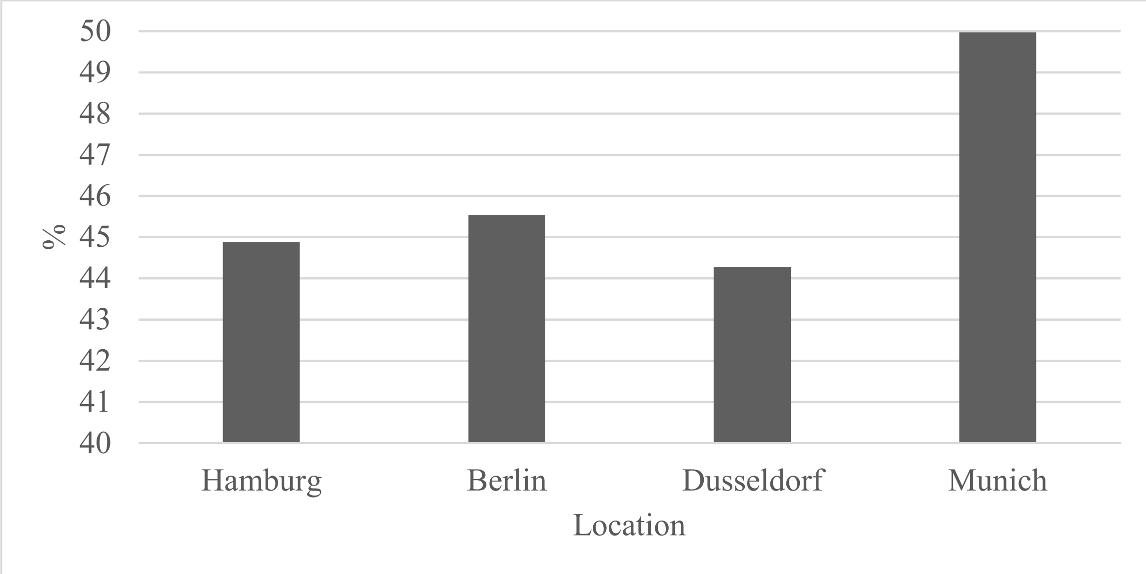

Figure 41: Solar fraction of the system

In Figure 40, the highest amount of energy is produced in Munich with almost 1.428 kWh and the lowest in Dusseldorf with 1.170 kWh. In Figure 41, it is shown that the solar fraction ranges from 44% to 50% with Munich presenting the highest one. This shows that the energy produced by the domestic solar hot water system in Munich is enough to cover 50% of the total energy demand compared to the other locations' demand. Hamburg has an energy demand of 2.770 kWh, Berlin 2.700 kWh, Dusseldorf 2.642 kWh while Munich has the highest with 2.857kWh. So even if Hamburg's energy production is more than Berlin's, the solar fraction of Hamburg is lower than it is in Berlin.

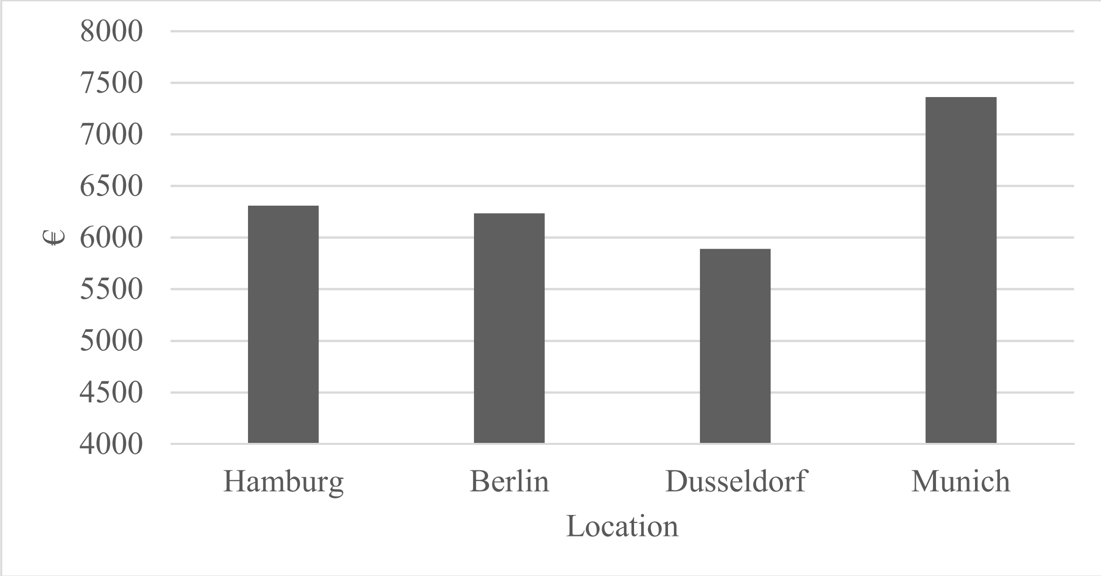

Figure 42: Net present value of the system

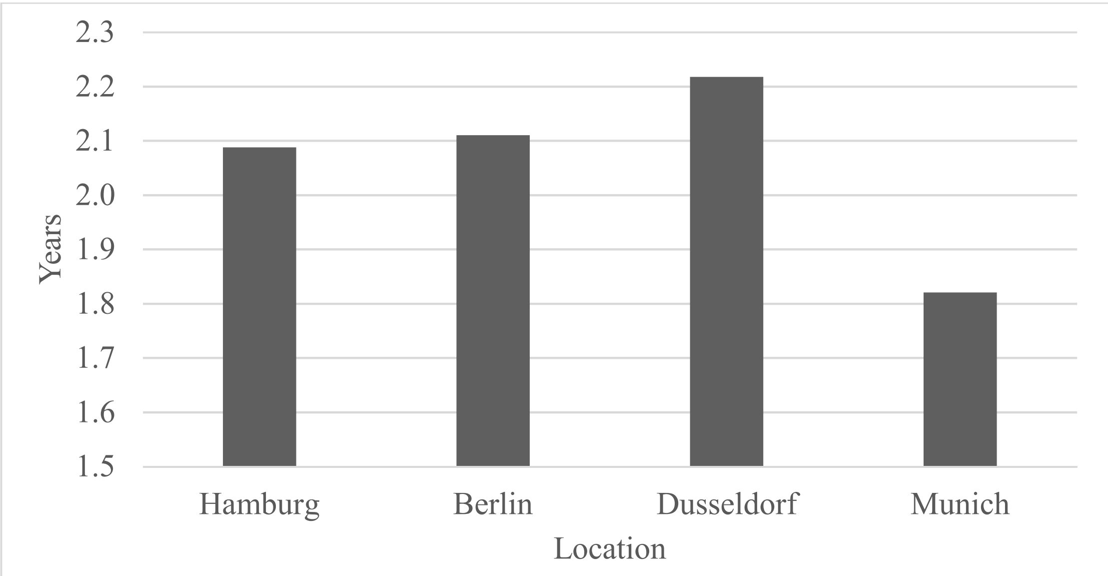

Figure 43: Payback period of the system

As presented in Figure 42, the highest net present value of the system is observed in Munich with almost 7.361€. That makes the project more economical feasible in this location due to higher energy production. In Figure 43, Munich has the lowest payback period of 1,8 years which is in accordance with Figure 42 that means where the economic benefits are higher the payback period will be shorter.

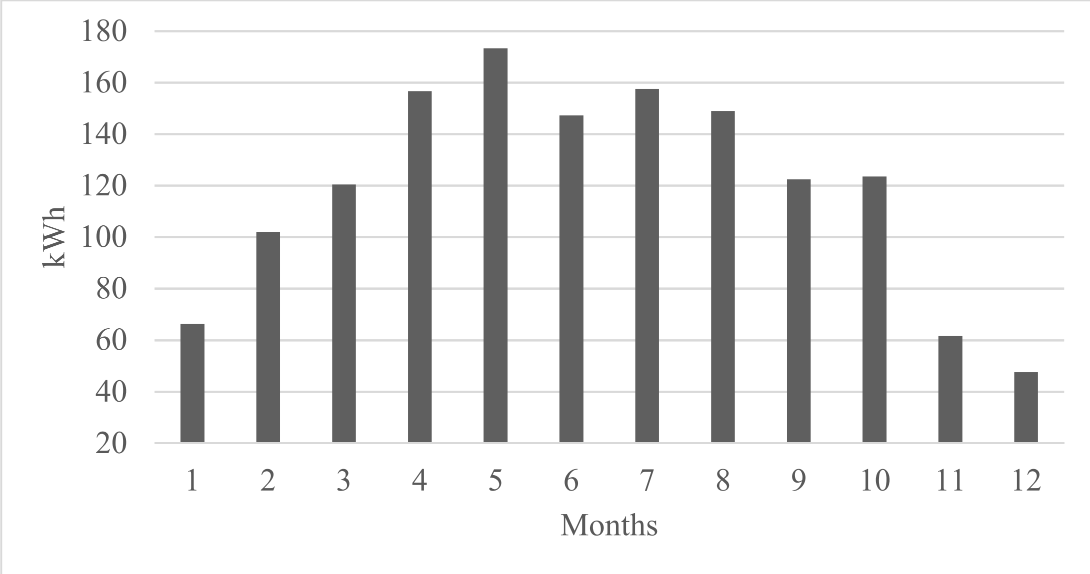

Figure 44: Monthly energy production of Munich

In Figure 44, it is evident that the energy produced by the domestic solar hot water system during the summer months ranging from 147 kWh to 157 kWh is more compared to the winter months ranging from 48 kWh to 102 kWh. The same trend more or less is observed in all locations across EU countries.

Having concluded with the base case scenario for each location a number of parametric simulations is made in order to examine the influence of different inputs to solar fraction, net present value and payback period of the domestic solar hot water system. The first parametric analysis has as input the number of collectors taking into consideration 1, 2 and 3 collectors. In addition, the next parametric analysis has as input the solar tank volumes including 0,18 m^3, 0,2 m^3 and 0,22 m^3 while the other parametric has as input the inclinations for the solar collectors ranging from 35° to 65° in steps of 5°. Finally, the last parametric has as input the number of occupants considering 3, 4 and 5 occupants regarding their average daily hot water usage of 150 kg/day, 200 kg/day and 250 kg/day respectively.

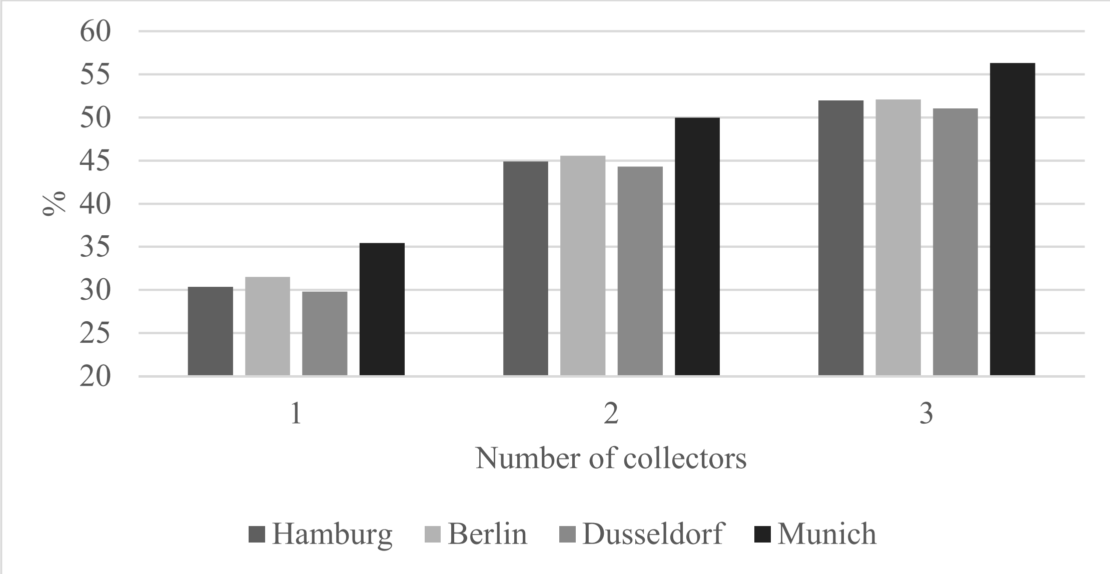

Figure 45: Solar fraction for different collectors

As shown in Figure 45, Munich presents the highest solar fraction in all cases with 35%, 50% and 57%. As the number of collectors increases, the solar fraction also does but not proportionately. Going from 1 collector to 2 collectors there is an increase of almost 15% but from 2 to 3 collectors the increase is 7%. During the summer months the energy demand is lower than the winter months. By having more than 2 collectors solar fraction will have a small increase since the energy produced by the system may increase but the demand is less than the winter months.

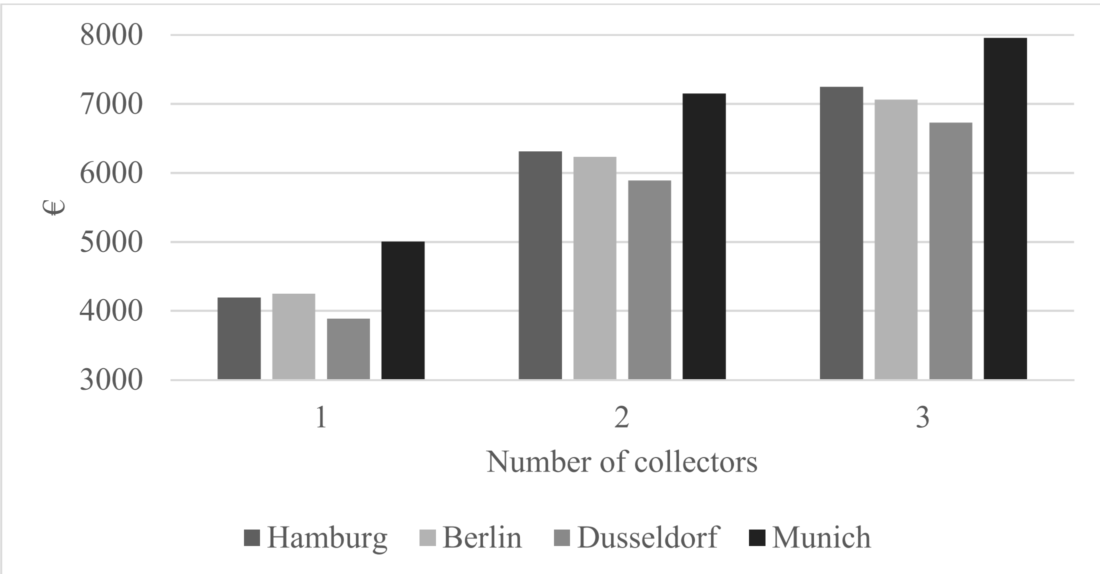

Figure 46: Net present value for different collectors

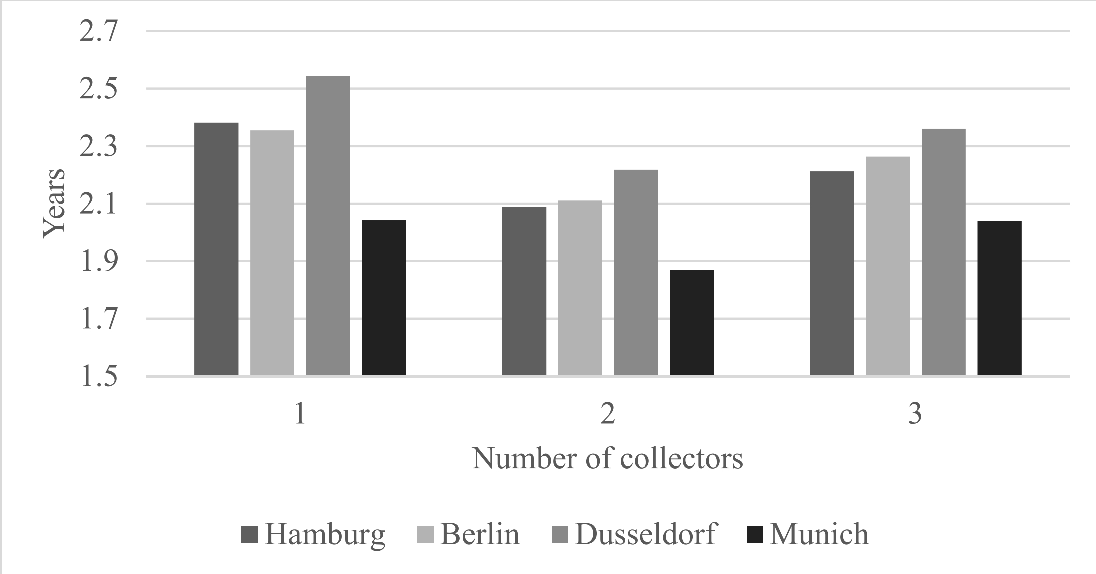

Figure 47: Payback period for different collectors

In Figure 46, the highest net present value is noticed in Munich with 5.000€, 7.148€ and almost 8.000€ that makes the project more economical feasible in the case of 3 collectors where more energy is produced. From Figure 46, it is evident that Munich presents the lowest payback period in all cases which follows the logic of where the economic benefit is higher the payback period will be shorter.

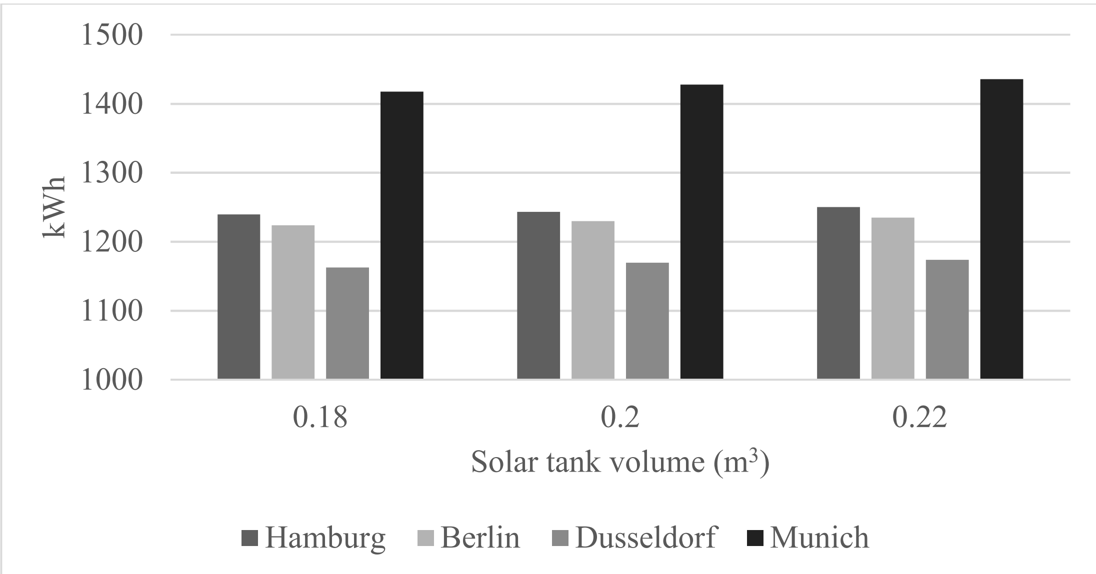

Figure 48: System energy for different solar tank volumes

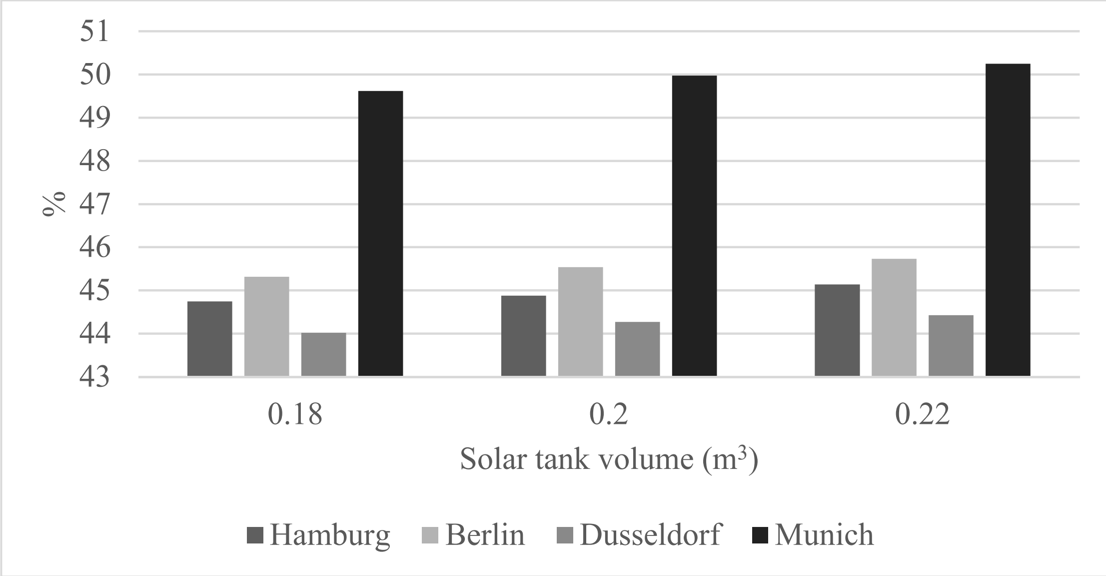

Figure 49: Solar fraction for different solar tank volumes

As shown in Figure 48, the total energy produced by the domestic solar hot water system does not present large differences while the solar tank volume increases since the only thing that changes is the volume where water is stored. Munich presents the highest values by 1.418 kWh, 1.428 kWh and 1.435 kWh. As presented in Figure 49, Munich has the highest solar fractions with 49%, 50% and almost 51% and that the increase in the solar tank volumes does not influence coverage as much because the difference among them is 0,02 m^3 and the energy input of the domestic solar hot water system has small changes.

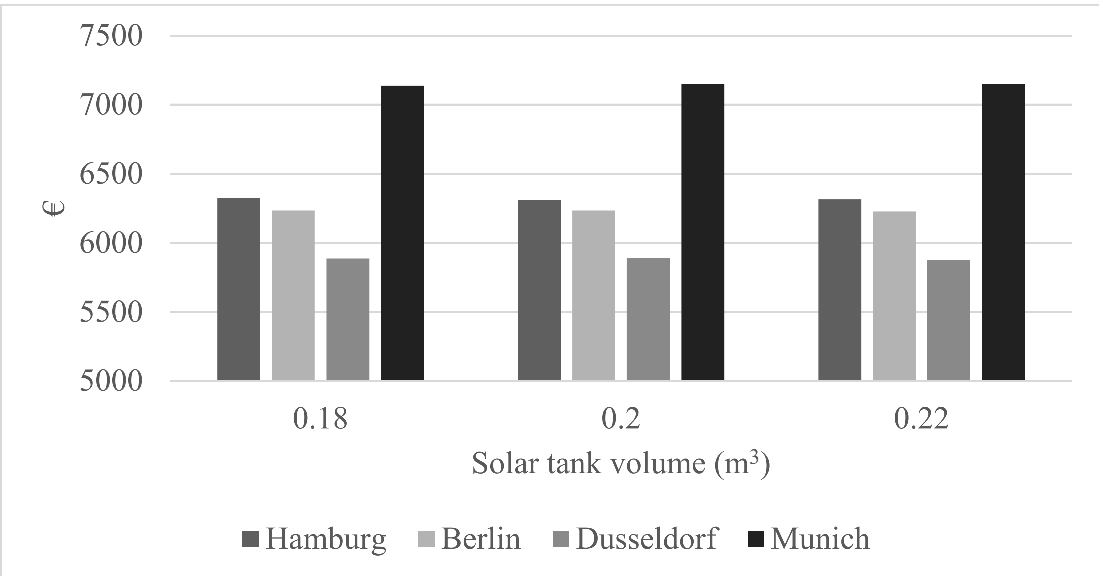

Figure 50: Net present value for different solar tank volumes

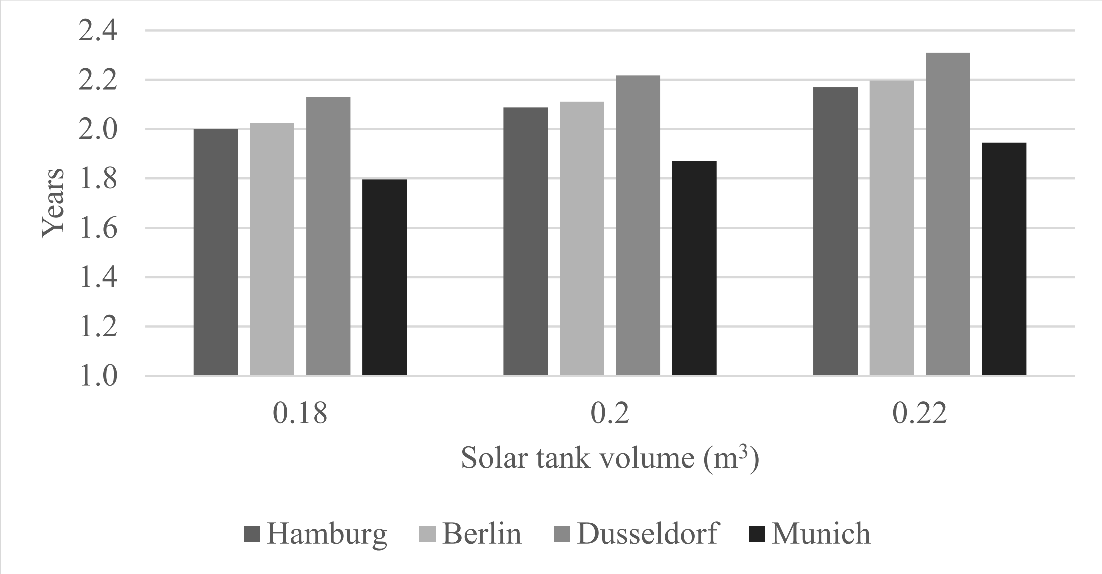

Figure 51: Payback period for different solar tank volumes

In Figure 50, it is shown that Munich presents the highest net present value with small changes making the project more economically feasible in this location and for this reason in Figure 51, Munich has the lowest payback period.

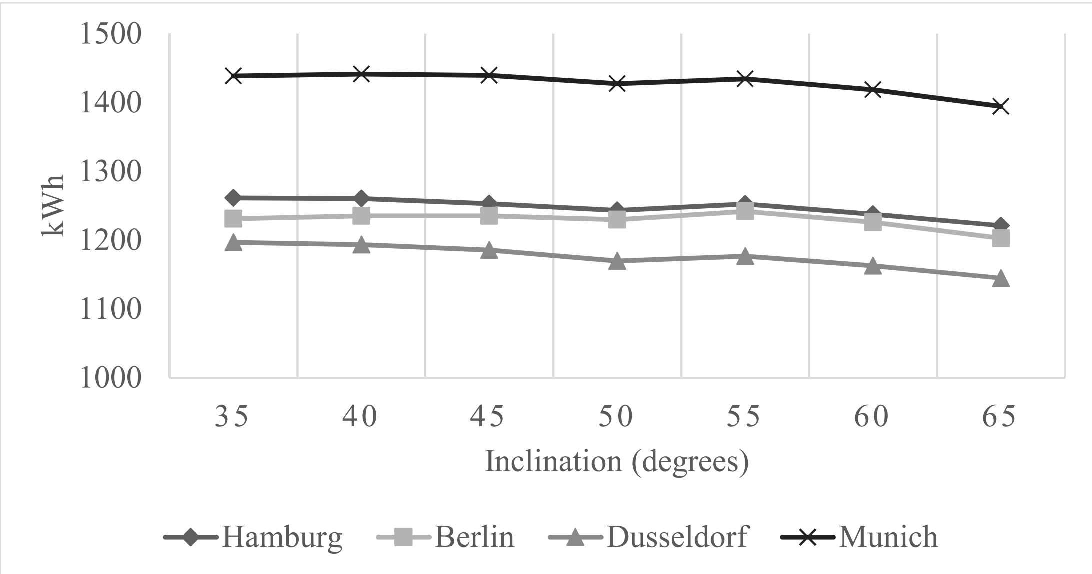

Figure 52: System energy for different inclinations

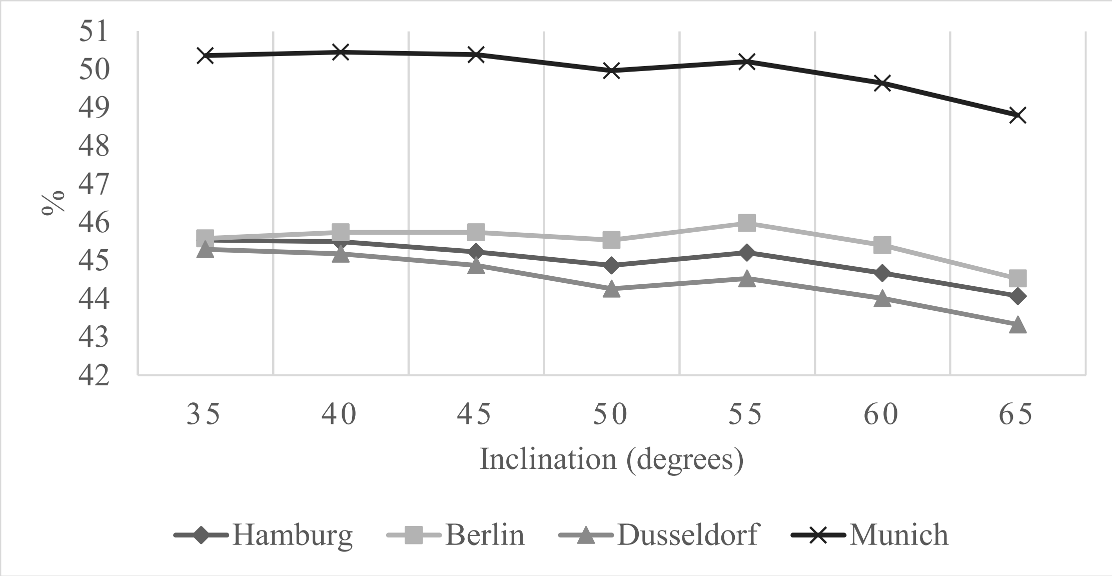

Figure 53: Solar fraction for different inclinations

In Figure 52, the most energy is observed to be produced in Munich in the case of 40° with 1.441 kWh while in Figure 53 the solar fraction is higher in Munich and the highest one is observed in 40° with 50,5%. The domestic solar hot water system produces more energy in Munich and at 40° it can take maximum solar radiation throughout the whole year compared to the other locations. In all cases it is observed that after 40° the solar fraction and the system energy is decreasing. The small increase between 50° and 55° is due to the fact that the locations may take advantage of solar radiation during winter months.

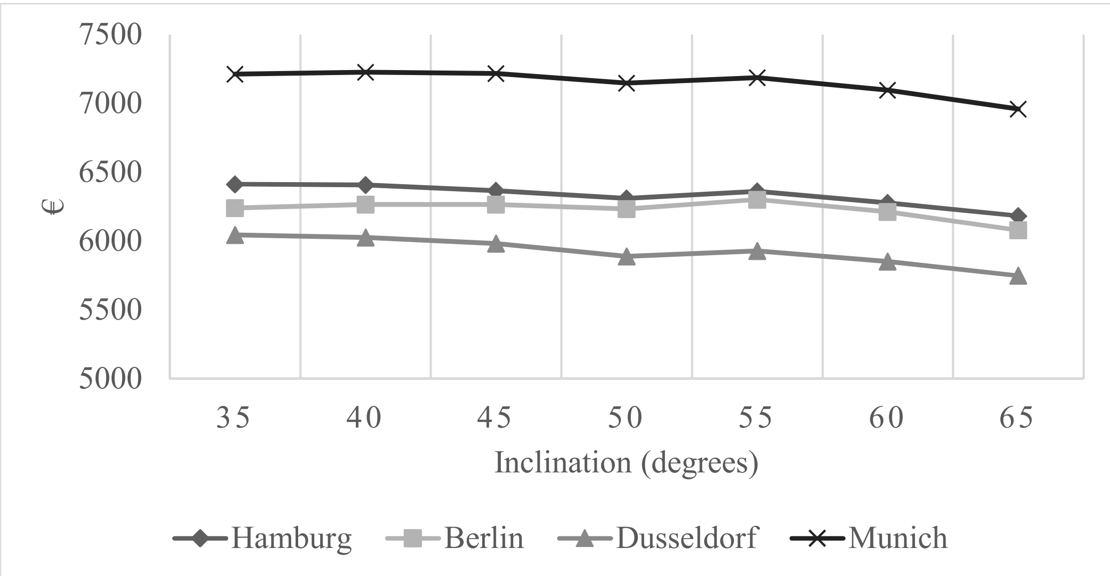

Figure 54: Net present value for different inclinations

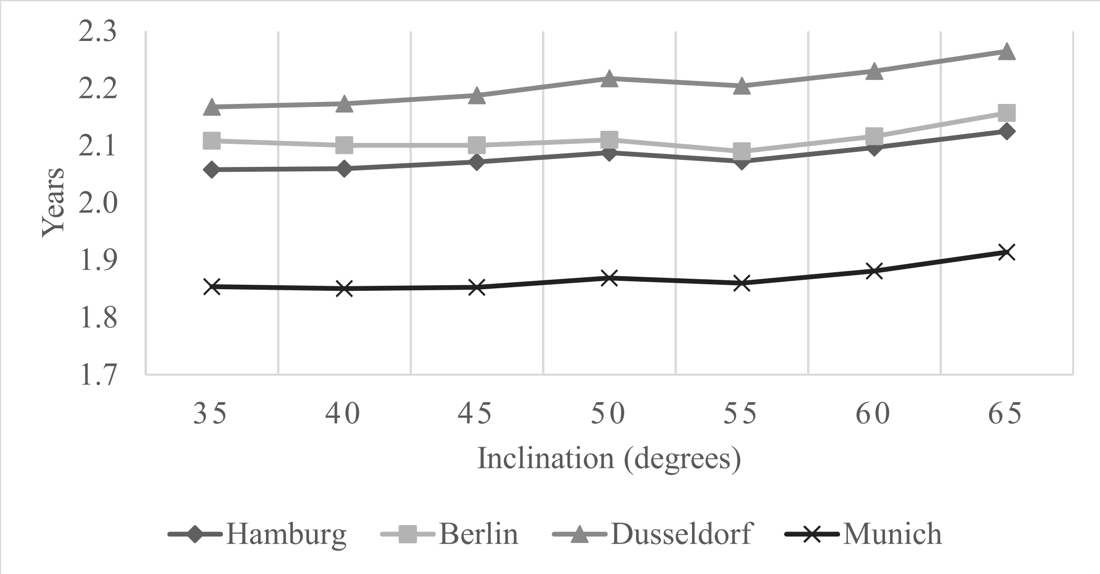

Figure 55: Payback period for different inclinations

In Figure 54, it is apparent that Munich presents the highest net present value without large differences among inclinations making the project more economically feasible and in Figure 55, the lowest payback period is also presented in Munich with almost 1.9 years because of where the economic benefits are higher the payback period will be shorter.

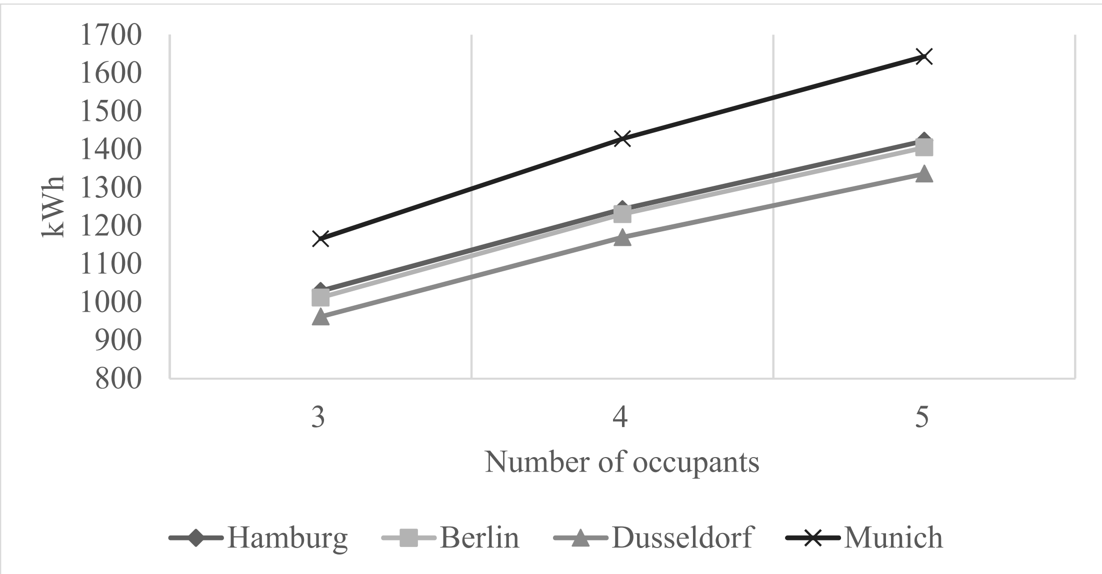

Figure 56: System energy for different occupants

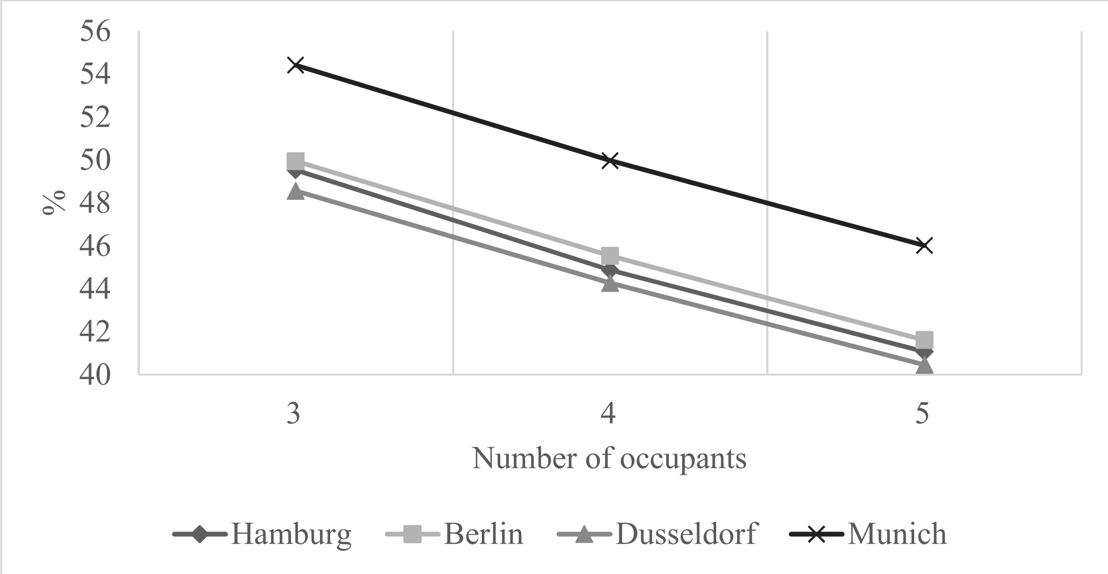

Figure 57: Solar fraction for different occupants

In Figure 56, it is apparent that the most energy is produced in Munich for 5 occupants reaching 1.643 kWh. Some solar gains that the domestic solar hot water system has during summer months may not be used and are lost. As the number of occupants increases, their energy demand also increases and these extra solar gains that were not previously used are in favor to cover the occupants' needs. Because of this in Figure 57, solar fraction presents a decrease as the number of occupants increases. Munich has the highest solar fraction observed for 3 occupants being 54% and their average daily hot water usage equals to 150 kg/day. Despite the fact that the energy produced by the system is increasing, the energy demand is higher and as a result the solar fraction is diminishing.

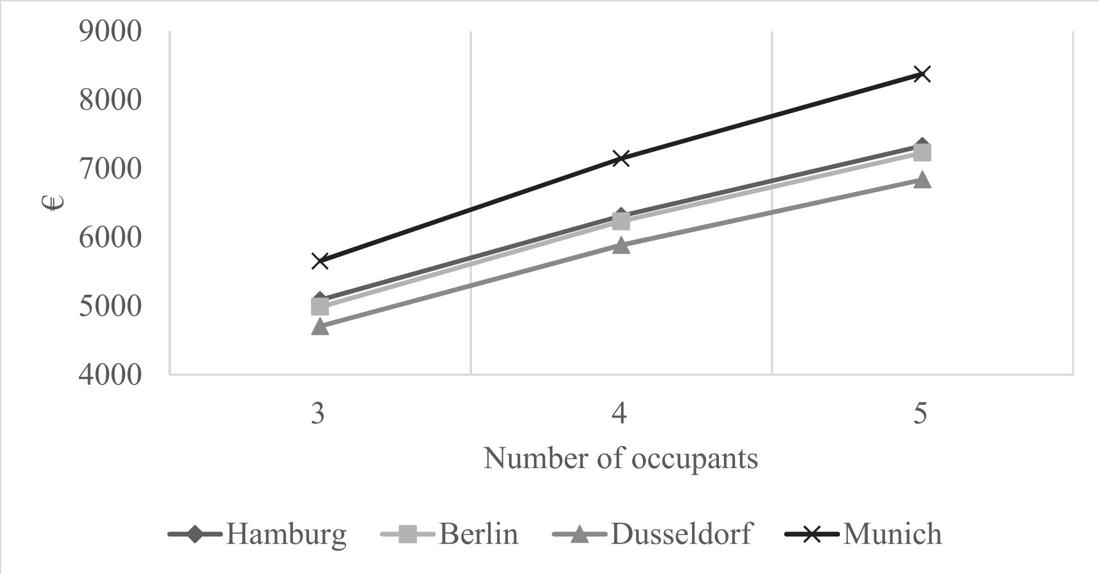

Figure 58: Net present value for different occupants

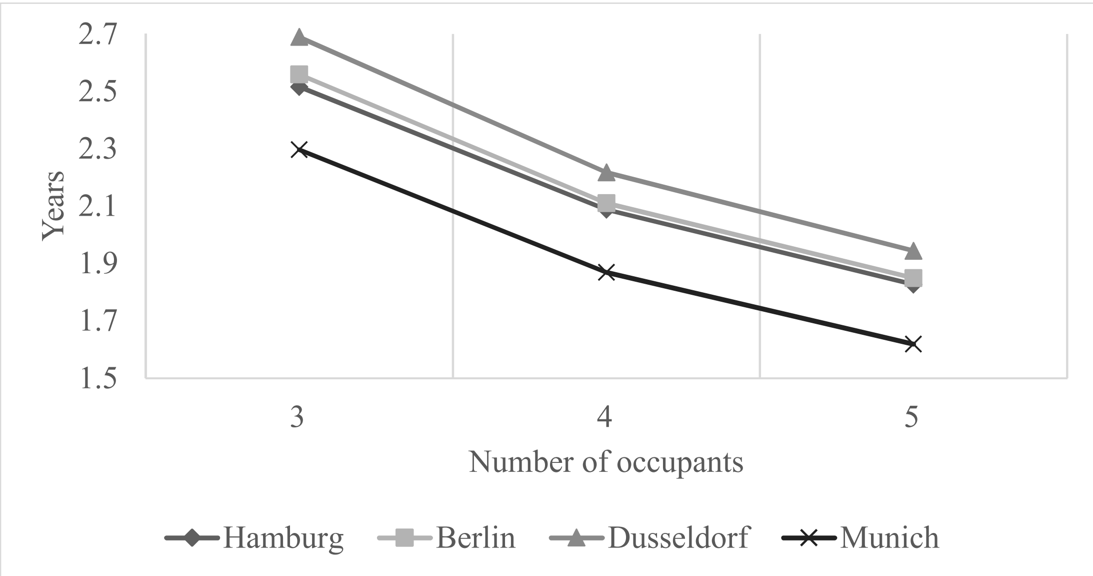

Figure 59: Payback period for different occupants

As shown in Figure 58, Munich has the highest net present value observed at 8.379€ for 5 occupants. This makes the project more economically feasible because of the more energy production for this case. In Figure 59, the payback period is lowest in Munich for 5 occupants for 1,6 years which is in accordance to where there are large economic benefits, the payback period will be shorter.

It can be concluded that among the four locations of Germany, the base case scenario (4 occupants, collector area= 4 m^2, $F_R(\tau\alpha)$= 0,76, F_RU_L= 4,5 W/m^2 C, inclination= 50º) presents better performance in Munich in all aspects. In the first parametric analysis, the system produces more energy in Munich in the case of 3 collectors and has also the highest solar fraction and net present value along with the shortest payback period. Furthermore, the next parametric analysis showed that for system energy Munich presents the highest one in 0,22 m^3. Additionally, the parametric analysis having as input the inclination of the system showed that Munich had the best results in 40° regarding all aspects. Munich is located at the center of Europe and is subject to many climatic influences. Its climate lies between the humid continental climate and the oceanic climate. The Alps affect Munich's climate in various ways and one of them is the warm downhill wind that can raise temperatures within a few hours even in the winter. Between 50° and 55° there is a small increase because of some potential solar earnings the system may have during winter months. Finally, in the parametric analysis for the number of occupants, Munich presents the highest value for 5 occupants in system energy. As the number of occupants increases, the system takes advantage of the solar gains which in other cases (3 or 4 occupants) are lost and raises its energy production. It has the highest solar fraction for 3 occupants. Even if the domestic solar hot water system produces more energy for 5 occupants, the energy demand for them remains higher. It is reasonable since the less the number of people and their average daily hot water usage of 150 kg/day, the domestic solar hot water system can provide more coverage for their needs. Munich has the highest net present value and lowest payback period for 5 occupants, following the essential of where the economic benefits are higher, the shorter is the payback period of the initial investment as electricity replacement.

Having calculated the solar fraction for various household types in four locations in Germany, a rough estimation of the total energy conservation that the use of solar thermal systems has in Germany is performed. According to the Federal Statistical Office of Germany [62] the average size of a typical household consists of 4 occupants. The average solar fraction of the locations that corresponds to this number of occupants is 46,2% which means that the amount of energy saved annually from a domestic solar hot water system similar to the base case scenario results to 1.267 kWh per system. Taking into consideration the total glazed area of the country and the residential energy consumption [63], the total energy conservation for all systems in Germany during the last 11 years is estimated.

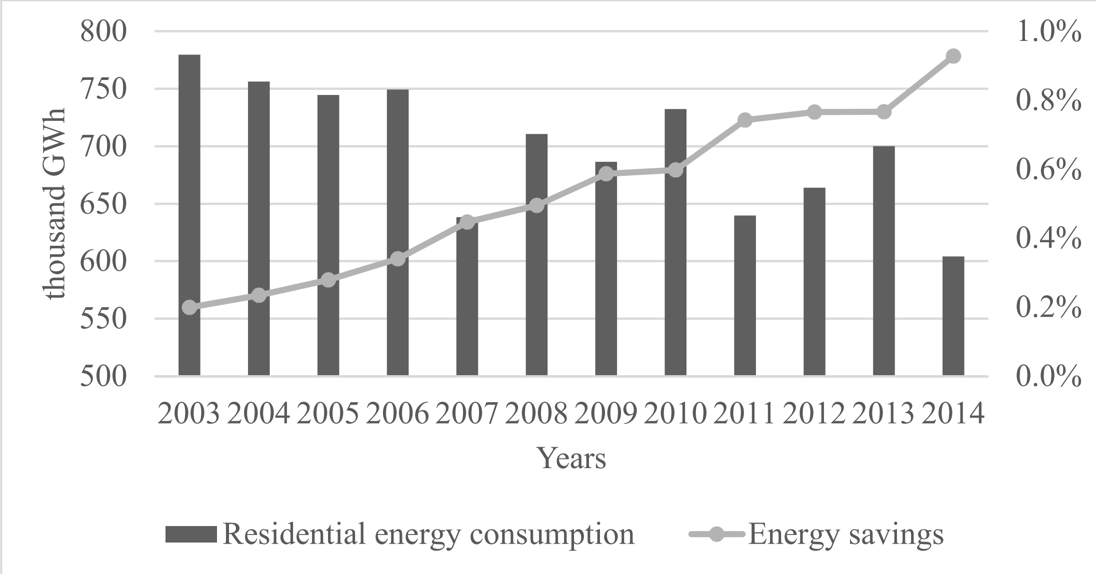

Figure 60: Total energy conservation

As presented in Figure 60, the total energy conservation increased during the last years as more systems were installed. It started with 1.551 GWh in 2003 and resulted to 5.602 GWh in 2014. Since 2003, energy consumption in the residential sector has started to decrease except for some annual increases like 2008, 2010 and 2013. The reduction was influenced by economic performance, lower heat consumption due to better climatic conditions, more efficient electrical appliances and heating systems. In 2003, the potential energy savings deriving from the domestic solar hot water systems accounted for 0,2% of the total residential energy consumption and reached to almost 0,9% of the total residential energy consumption in Germany in 2014.

In order to estimate the emissions reduction of GHG because of the domestic solar hot water systems usage, the emission factors for Germany per kWh of electricity generated were taken into consideration [64].

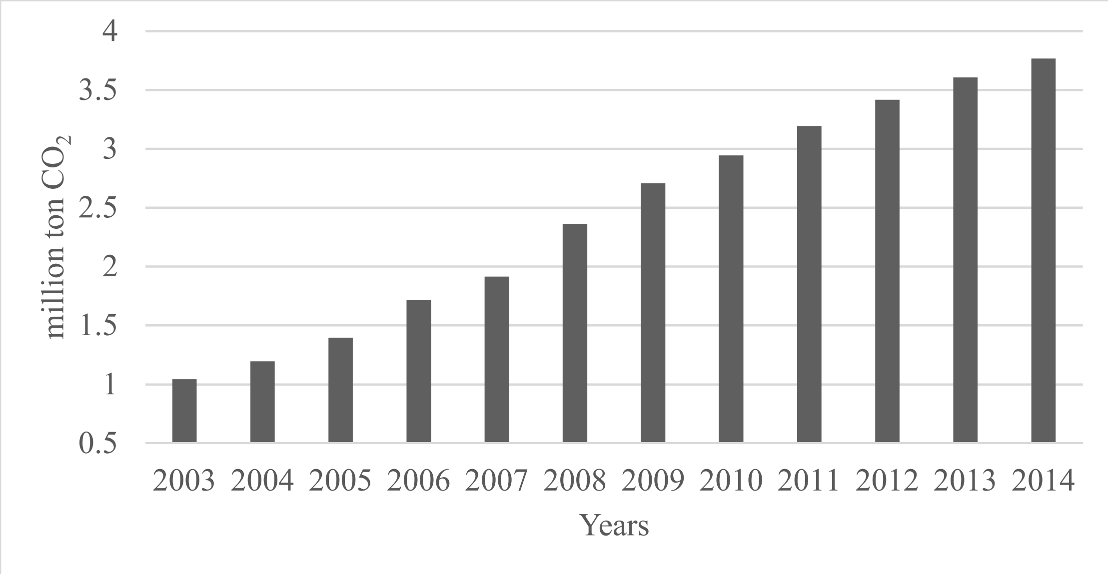

Figure 61: Tons of CO_2 saved

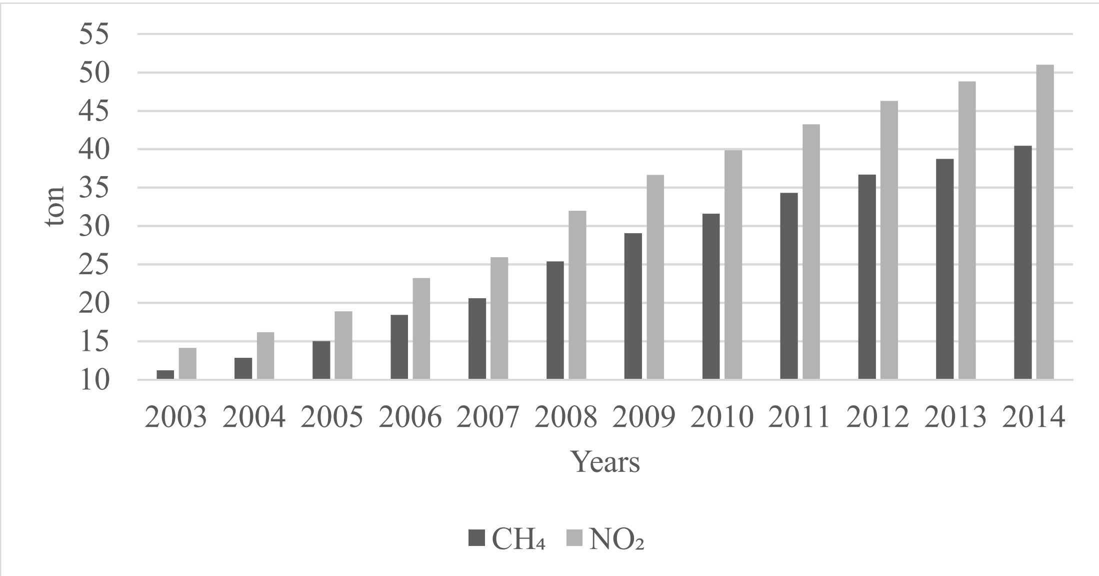

Figure 62: Tons of CH_4 and NO_2 saved

As presented in Figure 61, there was a steady increase of million tons of CO_2 saved by the domestic solar hot water systems usage from 2003 to 2014. It started with 1 million tons in 2003 and reached 3,7 million tons in 2014. The same happened with CH_4 and NO_2, as presented in Figure 62, that started with 11 and 14 tons in 2003 and reached 40 and 51 tons in 2014 respectively.

4.2. AUSTRIA

The locations examined for Austria are the metropolitan areas of Linz in Northern Austria, the capital Vienna and Innsbruck in Western Austria in order to cover all the different climatic conditions and for which full meteorological data in TMY format were available.

Table 4: Coordinates and elevation of locations

Location	Latitude	Longitude	Elevation
Linz	48,23°	14,20°	313 m
Vienna	48,12°	16,57°	190 m
Innsbruck	47,27°	11,35°	593 m

The latitude, longitude and elevation of each location are presented in Table 4. The electricity rate for Austria, incorporating all taxes and energy prices, is 0,198 €/kWh [60]. The inclination is set at 50° and the inflation rate is set at 1%/year [40, 72]. The average daily hot water usage is 50 kg/day/person and the solar tank has a volume of 0,2 m^3.

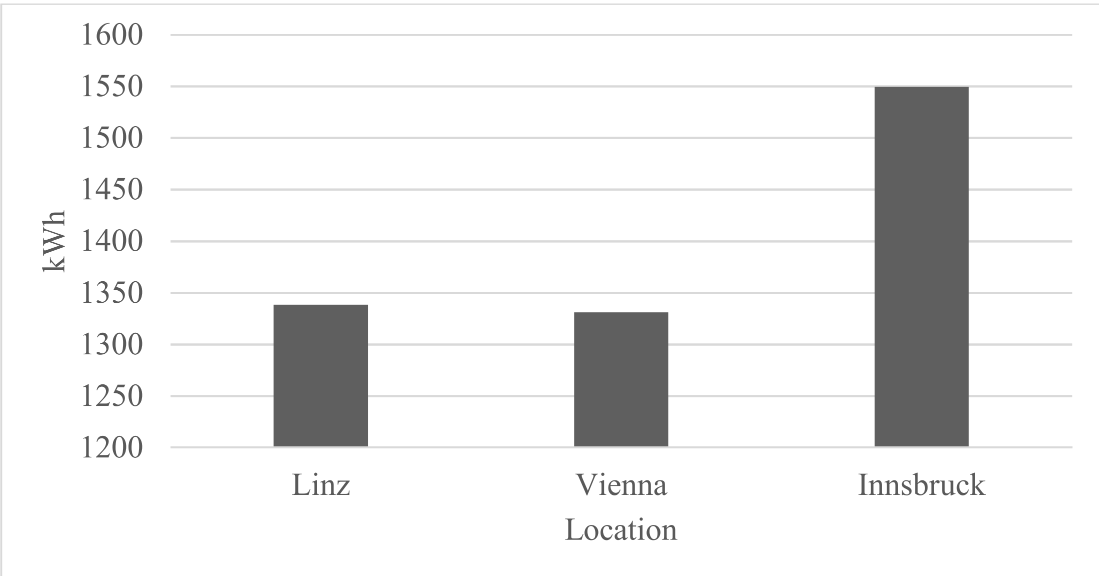

Figure 63: System energy

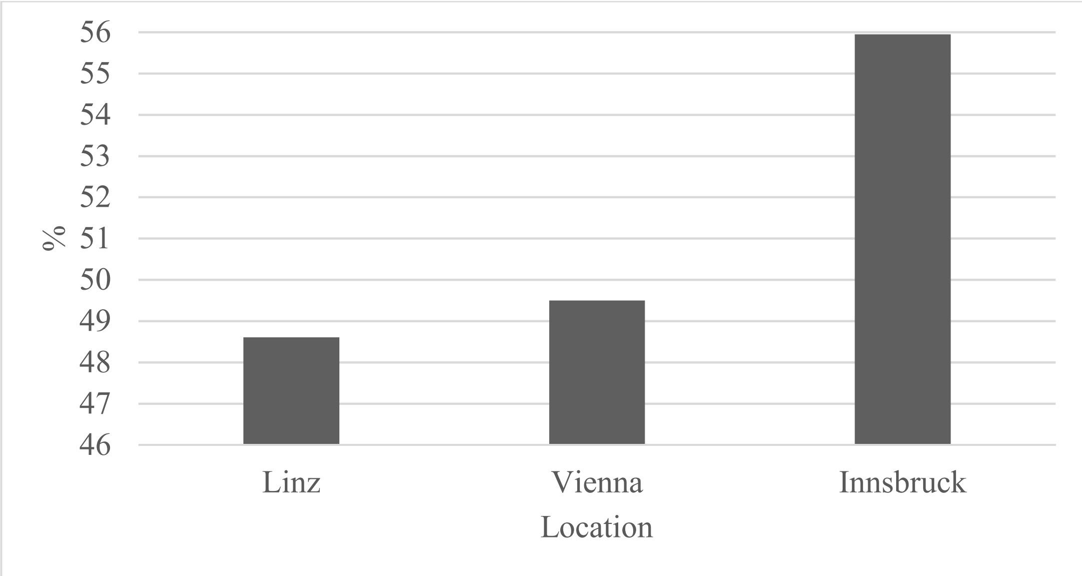

Figure 64: Solar fraction of the system

In Figure 63, it is evident that the highest amount of energy is produced in Innsbruck with almost 1.550 kWh. In Figure 64, it is shown that the solar fraction ranges from 48% to 56% with Innsbruck presenting the highest one. This shows that the energy produced by the domestic solar hot water system in Innsbruck is enough to cover 56% of the energy demand. Even if Innsbruck's energy demand is 2.769 kWh compared to 2.753 kwh of Linz and 2.688 kWh of Vienna, the energy produced by the domestic solar hot water system is larger and as result the solar fraction is higher.

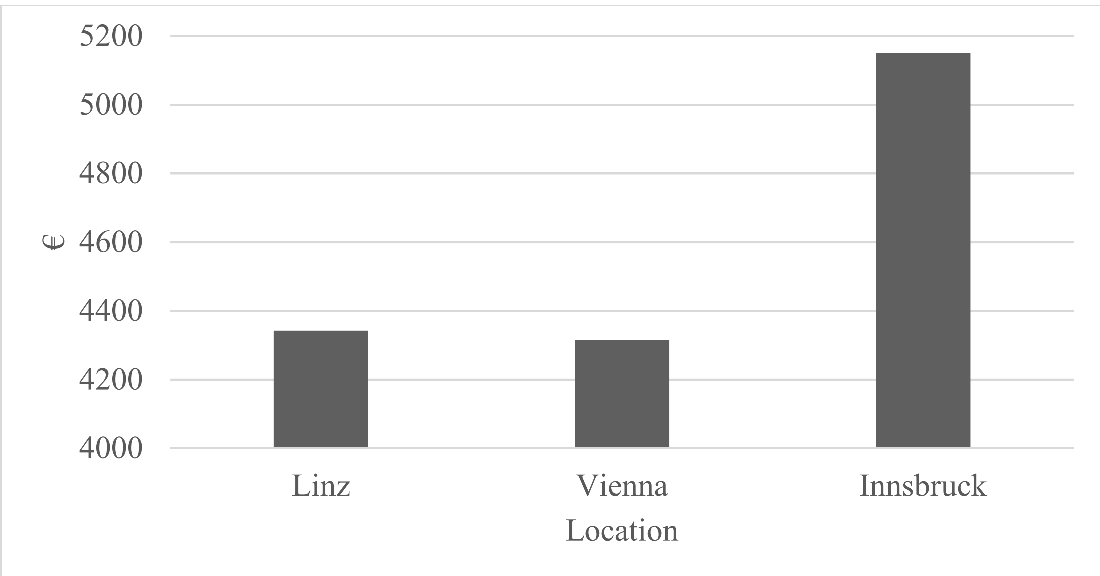

Figure 65: Net present value of the system

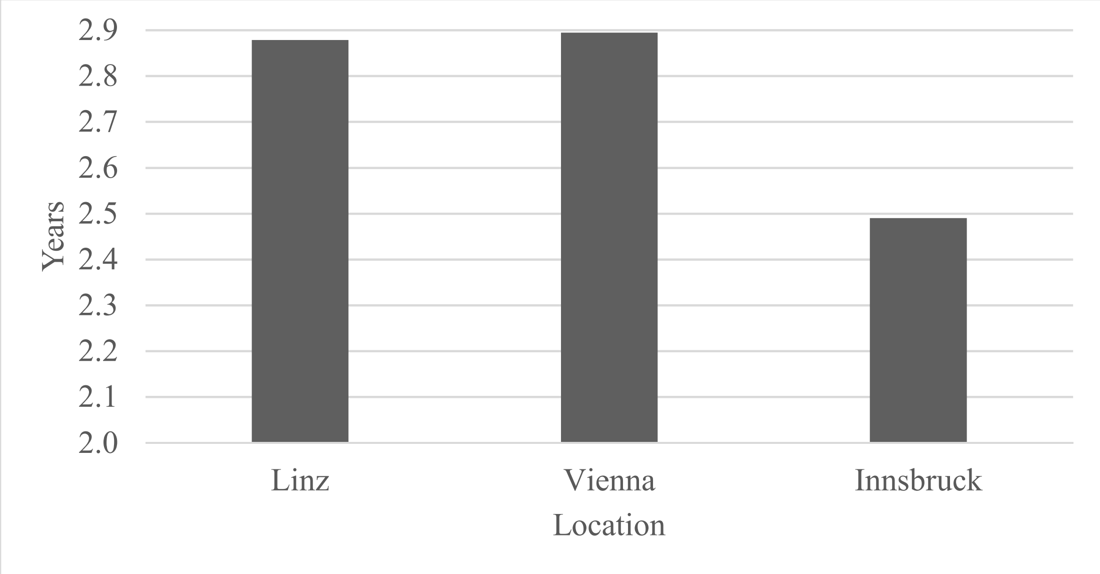

Figure 66: Payback period of the system

As presented in Figure 65, the highest net present value of the system is observed in Innsbruck with almost 5.151€. That makes the project more economical feasible in this location because of more energy production. In Figure 66, it is apparent that Innsbruck has the lowest payback period of almost 2,5 years that means where the economic benefits are higher the payback period will be shorter.

Having concluded with the base case scenario for each location a number of parametric simulations is made in order to examine the influence of different inputs to system energy, solar fraction, net present value and payback period of the domestic solar hot water system. The first parametric analysis has as input the number of collectors taking into consideration 1, 2 and 3 collectors. In addition, the next parametric analysis has as input the solar tank volumes including 0,18 m^3, 0,2 m^3 and 0,22 m^3 while the other parametric has as input the inclinations for the solar collectors ranging from 35° to 65° in steps of 5°. Finally, the last parametric has as input the number of occupants considering 3, 4 and 5 occupants regarding their average daily hot water usage of 150 kg/day, 200 kg/day and 250 kg/day respectively.

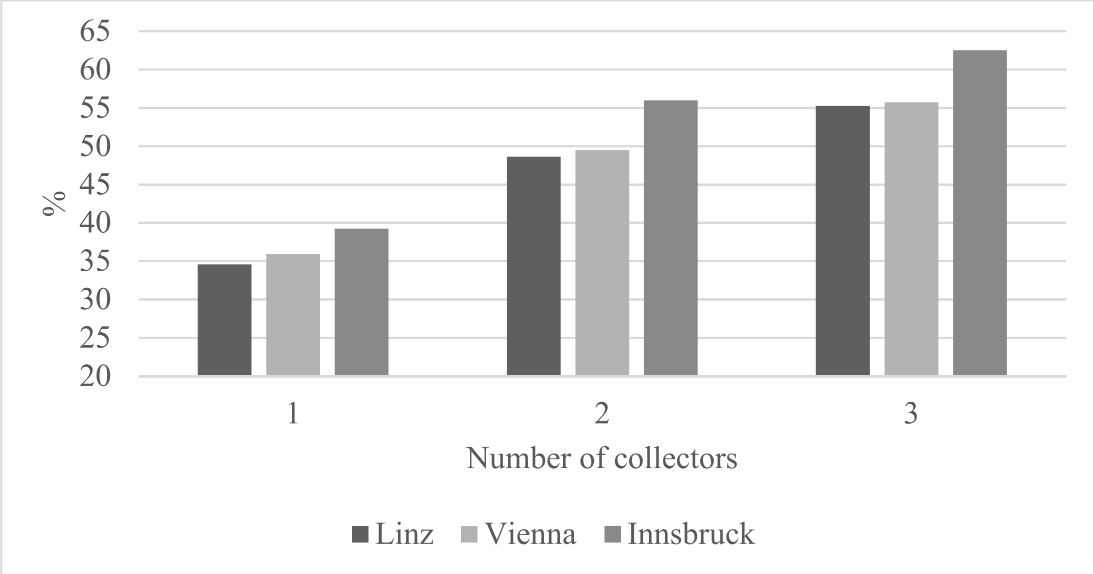

Figure 67: Solar fraction for different collectors

As shown in Figure 67, Innsbruck presents the highest solar fraction in all cases with 39%, 56% and 62,5%. As the number of collectors increases, the solar fraction also does but not proportionately. Going from 1 collector to 2 collectors there is an increase of almost 17% but from 2 to 3 collectors the increase is 6,5%. During the summer months the energy demand is lower than the winter months. By having more than 2 collectors solar fraction will have a small increase since the energy produced by the system may increase but the energy demand is less than the winter months.

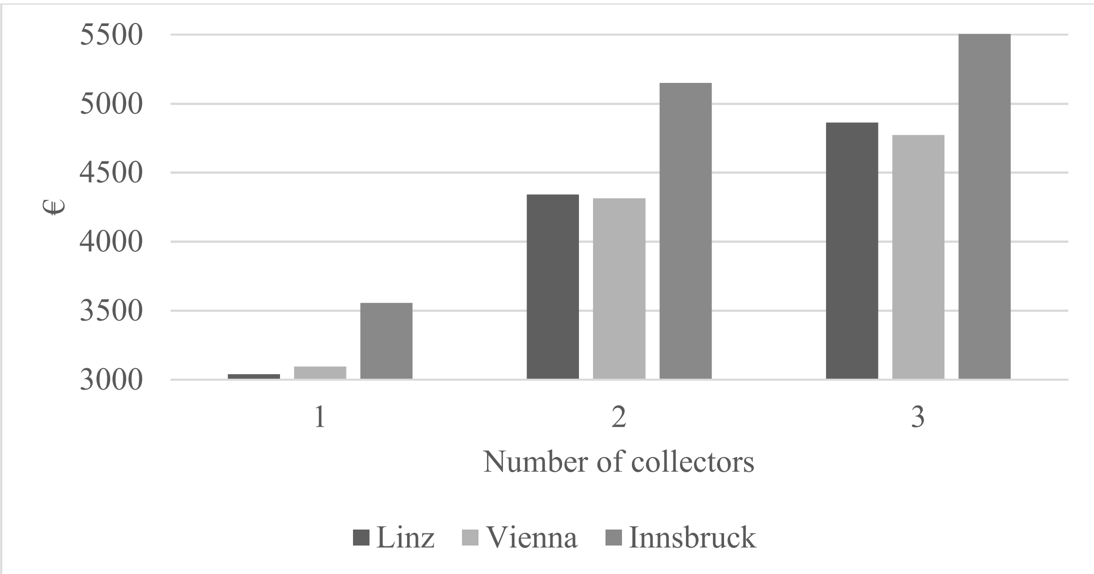

Figure 68: Net present value for different collectors

Figure 69: Payback period for different collectors

In Figure 68, the highest net present value is observed in Innsbruck with 3.500€, 5.150€ and 5.500€ that makes the project more economical feasible in the case of 3 collectors where the most energy is produced. From Figure 69, it is apparent that the shortest payback period is noticed in Innsbruck which follows the rational of where the economic benefits are higher the payback period will be smaller.

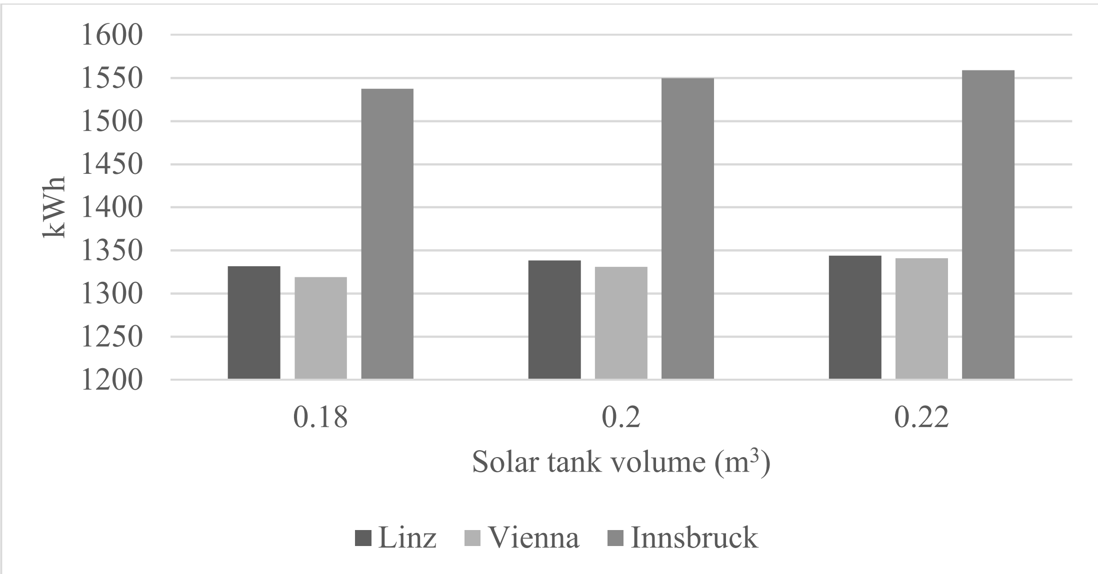

Figure70: System energy for different solar tank volumes

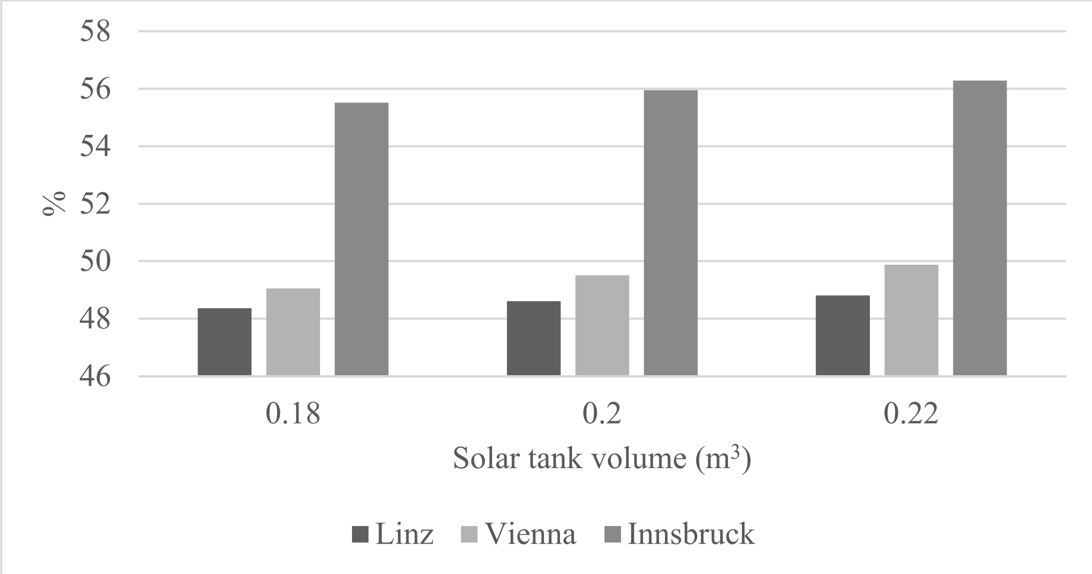

Figure 71: Solar fraction for different solar tank volumes

As shown in Figure 70, the energy produced by the system does not present large differences while the solar tank volume increases since the only thing that changes is the volume where water is stored. Innsbruck presents the highest values. As presented in Figure 71, Innsbruck has the highest solar fractions ranging from 55,5% to 56,2% and that the increase in the solar tank volumes does not influence coverage as much because the difference among them is 0,02 m^3 and the energy input of the domestic solar hot water system has small changes of 10 kWh.

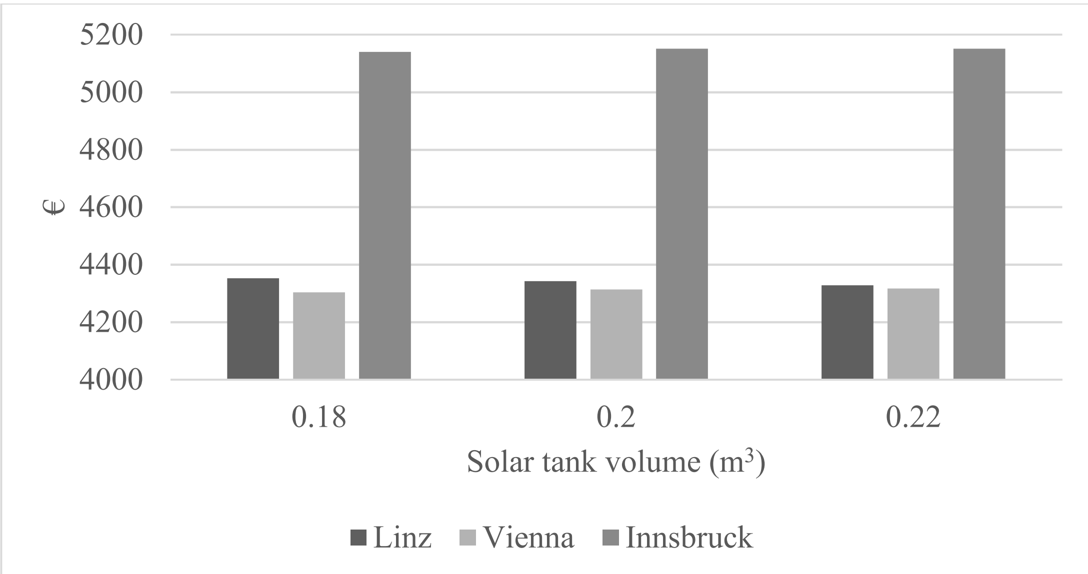

Figure 72: Net present value for different solar tank volumes

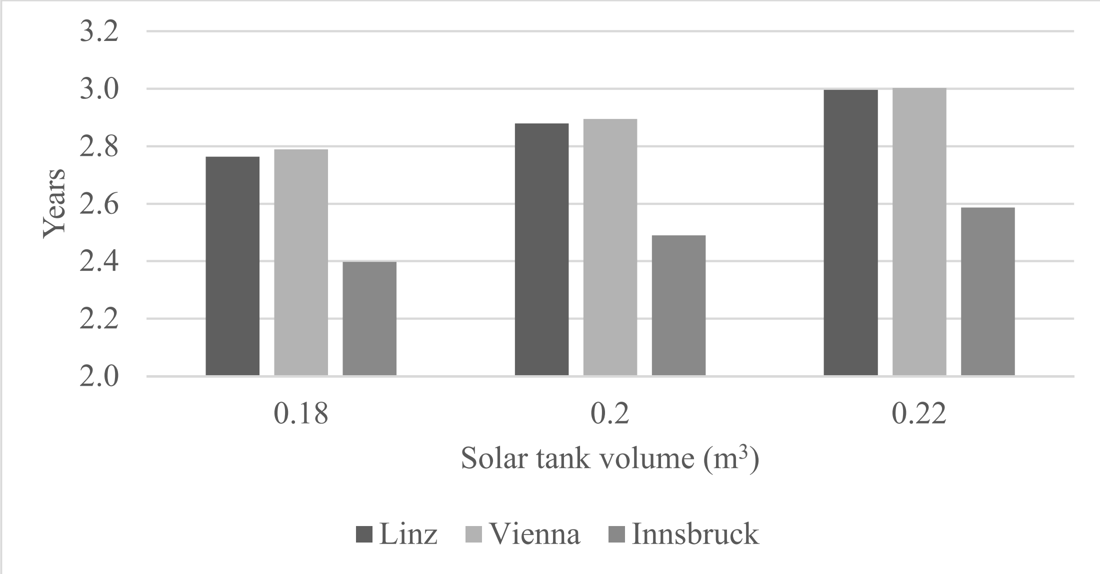

Figure 73: Payback period for different solar tank volumes

In Figure 72, the highest net present value is observed in Innsbruck with small differences and for this reason in Figure 73, Innsbruck has also the lowest payback period without large changes.

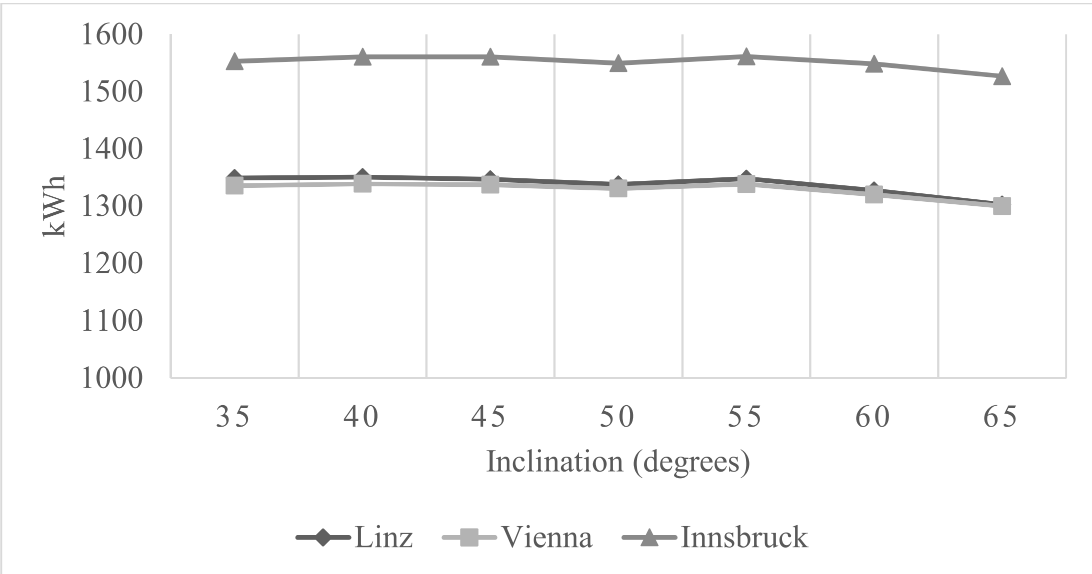

Figure 74: System energy for different inclinations

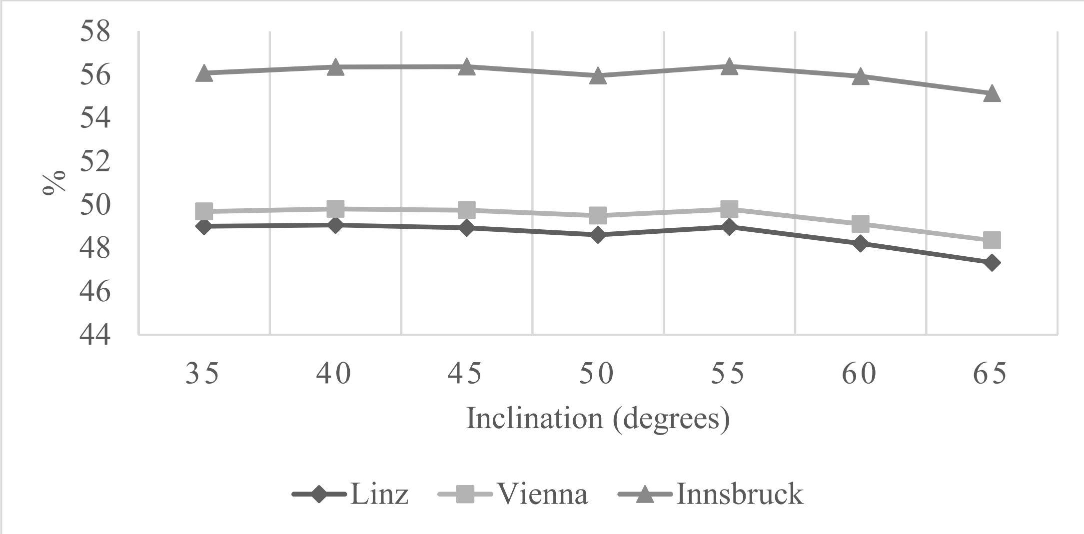

Figure 75: Solar fraction for different inclinations

In Figure 74, it is apparent that the most energy is produced in Innsbruck in the case of 55º with 1.562 kWh while in Figure 75 the solar fraction is higher in Innsbruck in 55º with 56,4%. The domestic solar hot water system in Innsbruck at 55º can take maximum solar radiation throughout the whole year compared to the other locations even in winter months. In all cases it is observed that after 55º the solar fraction and the system energy is decreasing. The small increase between 50º and 55º is due to the fact that the locations may take advantage of solar radiation during winter months.

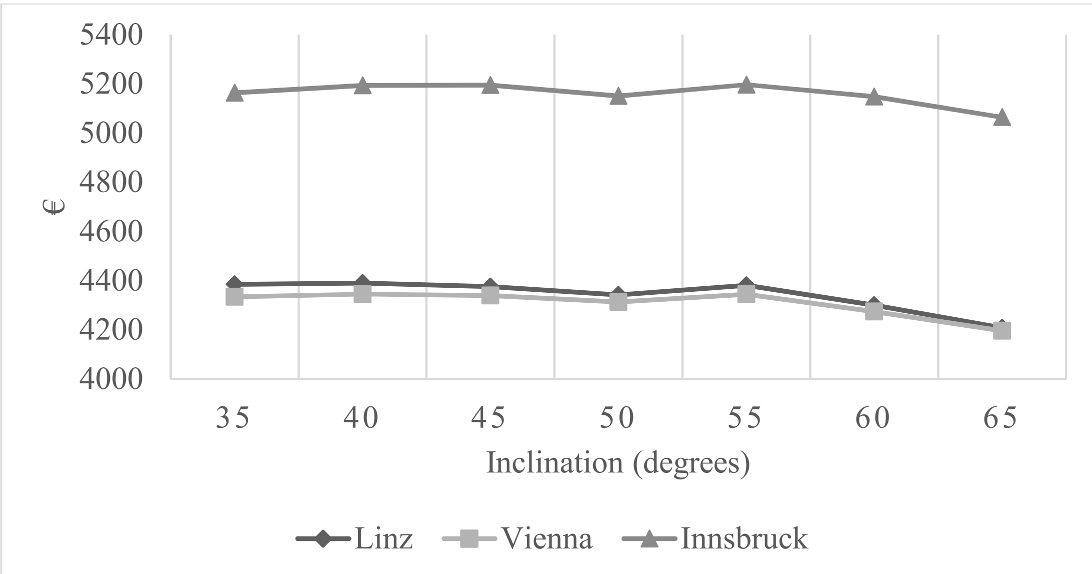

Figure 76: Net present value for different inclinations

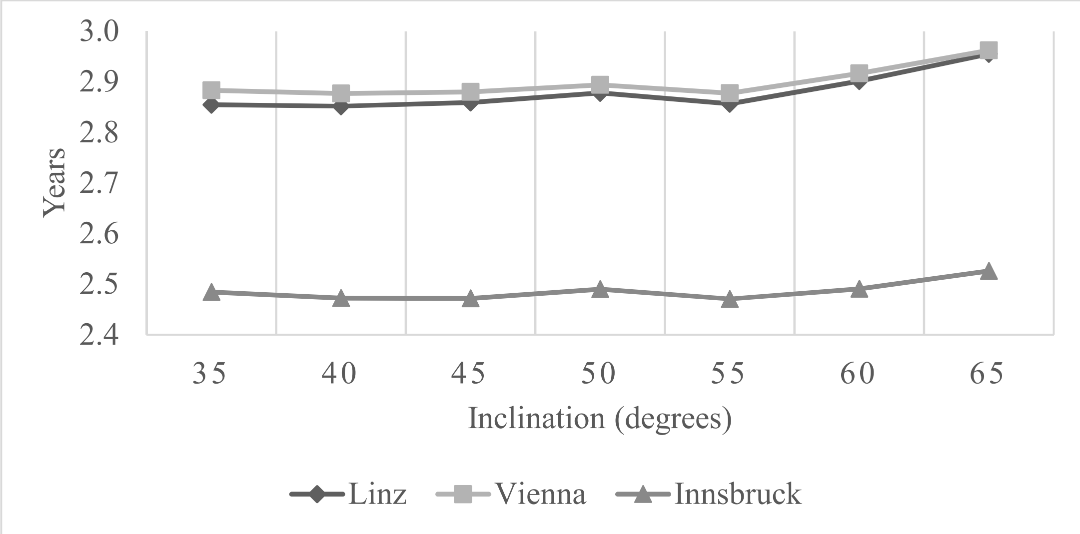

Figure 77: Payback period for different inclinations

In Figure 76, it is apparent that Innsbruck presents the highest net present value noticed in 55º with 5.197€ making the project more economically feasible because the energy produced in this angle is higher and in Figure 77, the lowest payback period is in Innsbruck in the case of 55º with almost 2,5 years for the reason that where the economic benefit is higher the payback will be shorter.

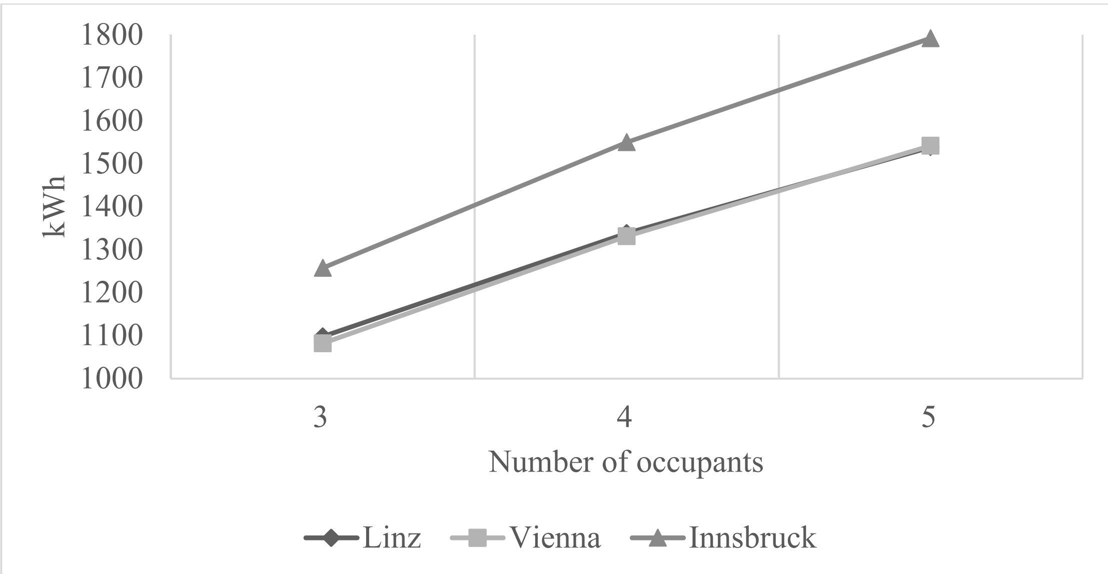

Figure 78: System energy for different occupants

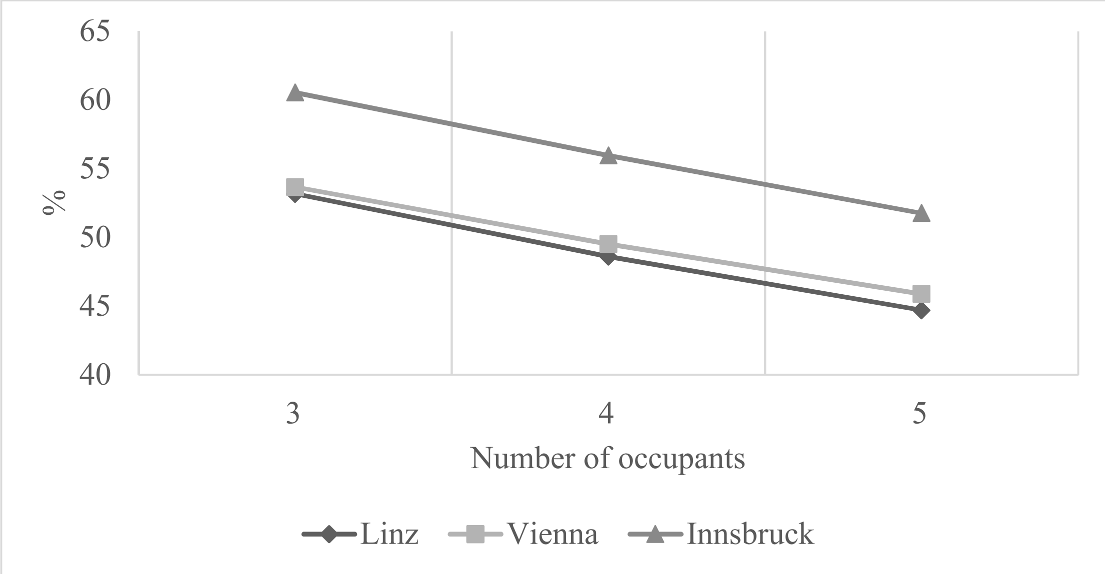

Figure 79: Solar fraction for different occupants

In Figure 78, it is evident that the most energy is produced in Innsbruck for 5 occupants reaching 1.792 kWh. Some solar gains that the domestic solar hot water system has during summer months may not be used and are lost. As the number of occupants increases, their energy demand also increases and these extra solar gains that were not previously used are in favor to cover the occupants' needs. In Figure 79, solar fraction presents a decrease as the number of occupants increases. Innsbruck has the highest solar fraction observed for 3 occupants being 60,5% and their average hot water usage equals to 150 kg/day. Despite the fact that the energy produced by the system is increasing, the energy demand is higher and as a result the solar fraction is diminishing.

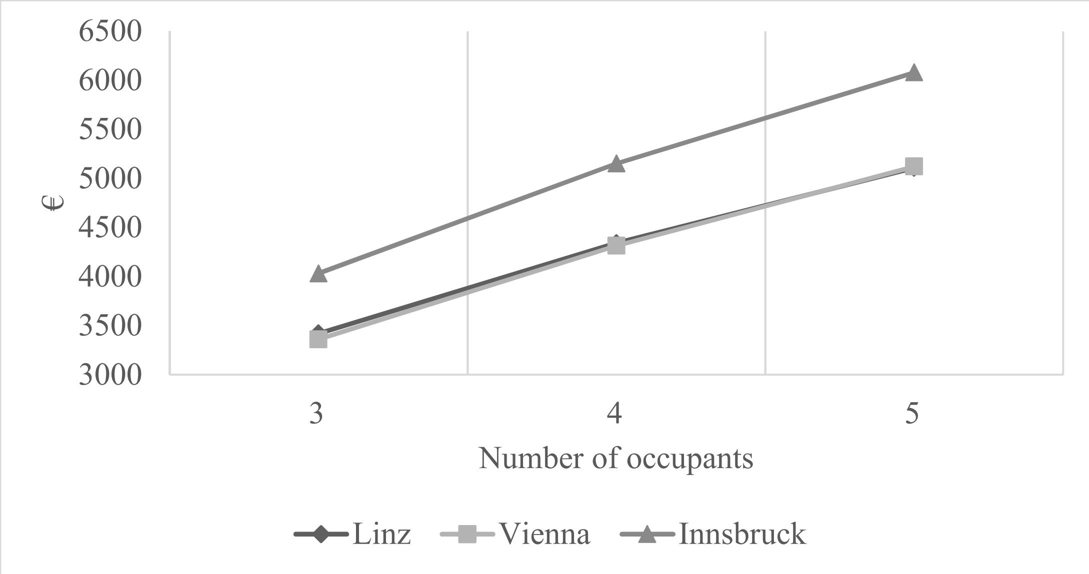

Figure 80: Net present value for different occupants

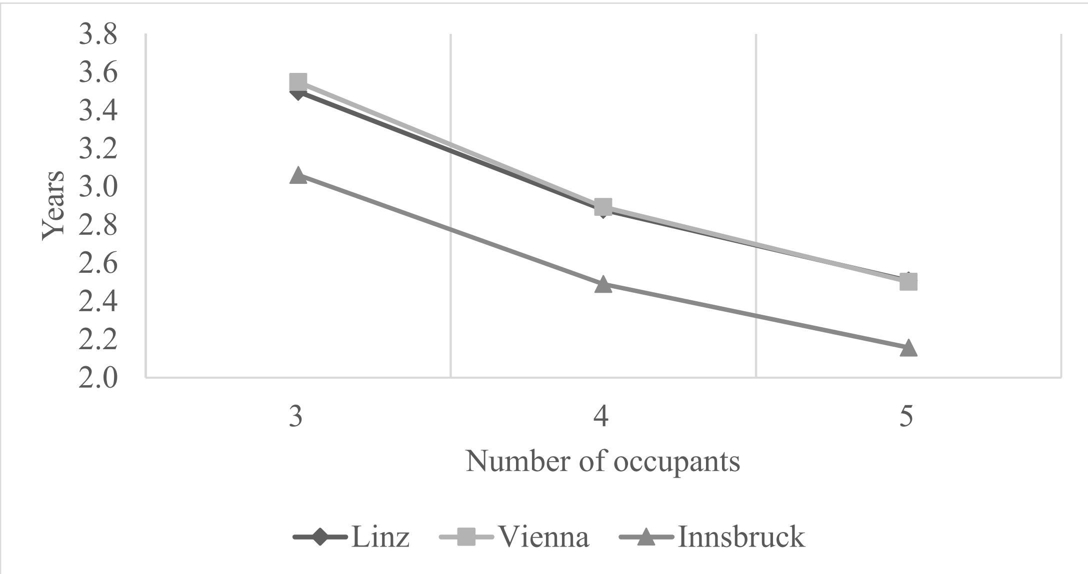

Figure 81: Payback period for different occupants

As shown in Figure 80, Innsbruck has the highest net present value observed at 6.079€ for 5 occupants. This makes the project more economically feasible since the energy produced by the system in this case is the highest one. In Figure 81, the payback period is lowest in Innsbruck for 5 occupants for 2,1 years which is in accordance to where there are large economic benefits, the payback period will be shorter.

It can be concluded that among the three locations of Austria, the base case scenario (4 occupants, collector area= 4 m^2, $F_R(\tau\alpha)$= 0,76, F_RU_L= 4,5 W/m^2 C, inclination= 50º) presents better performance in Innsbruck in all aspects. In the first parametric analysis, the system produces more energy in Innsbruck in the case of 3 collectors and has also the highest solar fraction, net present value along with the shortest payback period. Furthermore, the next parametric analysis showed that for system energy Innsbruck presents the highest one. Additionally, the parametric analysis having as input the inclination of the system showed that Innsbruck had the best results in 55^{o}.Innsbruck is located in the Central Europe around mountainous terrains having a continental climate with large annual temperature differences. Between 45^{o} and 50^{o} there is a small increase because of some potential solar earnings the system may have during winter months. Finally, in the parametric analysis for the number of occupants, Innsbruck presents the highest value for 5 occupants in system energy. As the number of occupants increases, the system takes advantage of the solar gains which in other cases (3 or 4 occupants) are lost and raises its energy production. Innsbruck has the highest solar fraction for 3 occupants. Even if the domestic solar hot water system produces more energy for 5 occupants, the energy required for them is remains higher. It is reasonable since the less the number of people and their average daily hot water usage of 150 kg/day, the domestic solar hot water system can provide more coverage for their needs. Innsbruck presents the highest net present value and the shortest payback period for 5 occupants following the essential of where the economic benefits are higher, the shorter is the payback period of the initial investment as electricity replacement.

Having calculated the solar fraction for various household types in three locations in Austria, a rough estimation of the total energy conservation that the use of solar thermal systems has in Austria is performed. According to the Austrian Statistical Office [65] the average size of a typical household consists of 3 occupants. The average solar fraction of the locations that corresponds to this number of occupants is 55,8% which means that the amount of energy saved annually from a domestic solar hot water system similar to the base case scenario results to 1.146 kWh per system. Taking into consideration the total glazed area of the country and the residential energy consumption [63], the total energy conservation for all systems in Austria during the last 11 years is estimated.

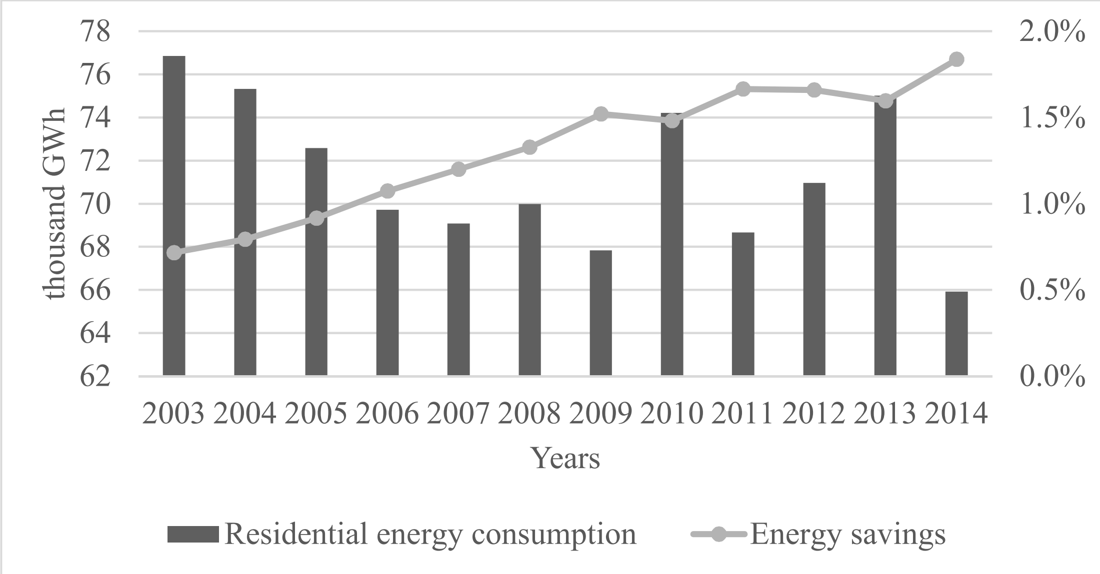

Figure 82: Total energy conservation

As presented in Figure 82, the total energy conservation increased during the last years as more systems were installed. It started with 551 GWh in 2003, it remained steady and resulted to 1.211 GWh in 2014. Since 2003, energy consumption in the residential sector has started to decrease except for some increases like 2008, 2010, 2012 and 2013. The reduction was influenced by economic performance, lower heat consumption due to better climatic conditions, more efficient electrical appliances and heating systems. In 2003, the potential energy savings deriving from the domestic solar hot water systems accounted for 0.7% of the total residential energy consumption. These savings reached to 1.8% of the total residential energy consumption in Austria in 2014.

In order to estimate the emissions reduction of GHG because of the domestic solar hot water systems usage, the emission factors for Austria per kWh of electricity generated were taken into consideration [64].

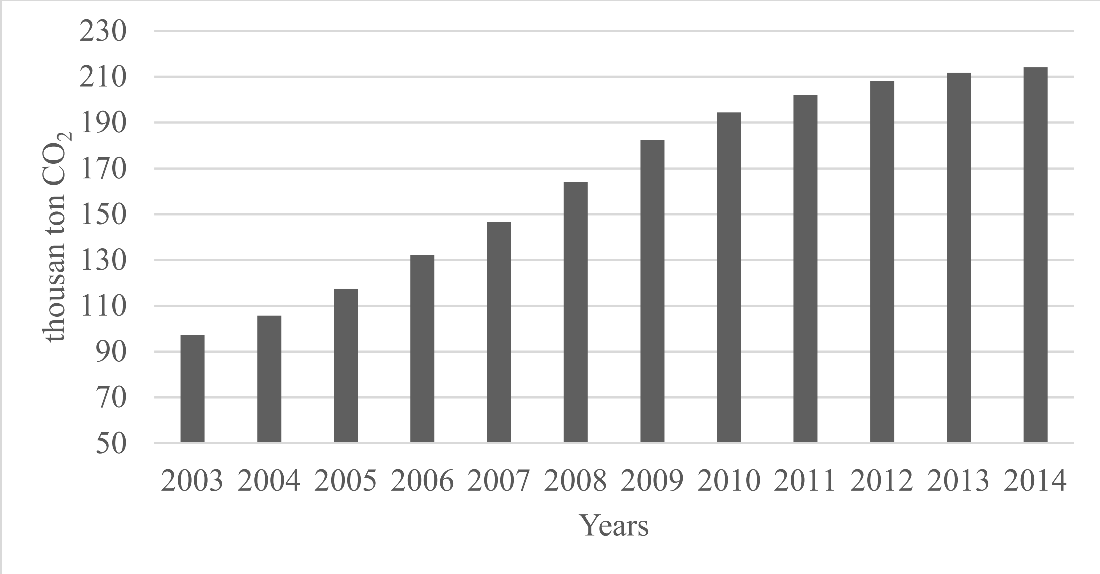

Figure 83: Tons of CO_2 saved

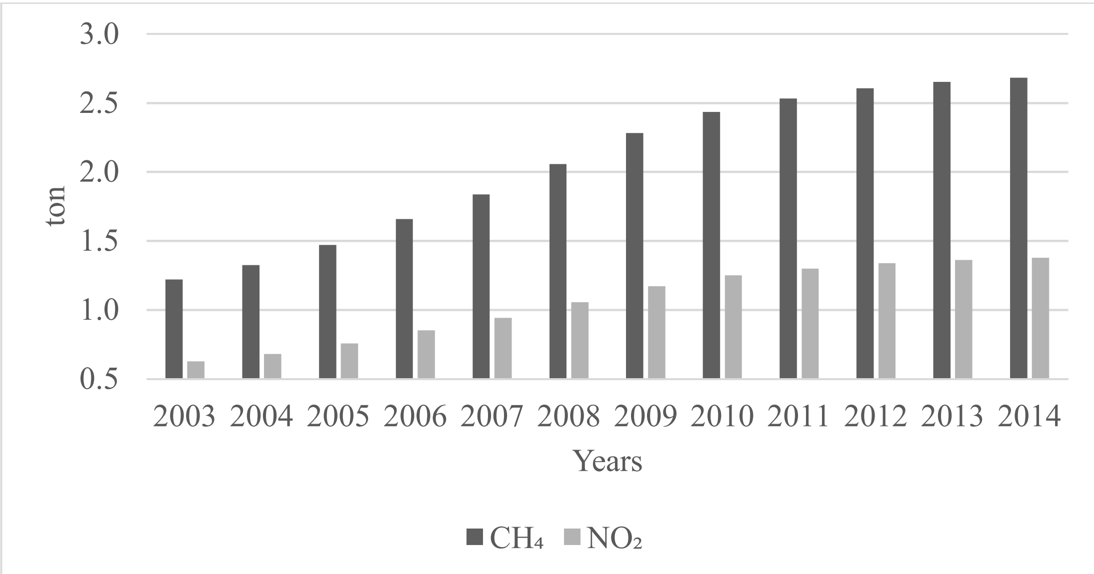

Figure 84: Tons of CH_4 and NO_2 saved

As presented in Figure 83, there was a steady increase for thousand tons of CO_2 saved by the domestic solar hot water systems usage from 2003 to 2014. It started with 97 thousand tons in 2003 and reached almost 214 thousand tons in 2014. The same happened with CH_4 and NO_2, as presented in Figure 84, that started with 1,2 and 0,6 tons in 2003 and reached 2,7 and 1,4 tons in 2014 respectively.

4.3. GREECE

The locations examined for Greece are the metropolitan areas of Thessaloniki in Northern Greece, the capital Athens in Central Greece and Andravida near Patra in Western Greece in order to cover all the different climatic conditions and for which full meteorological data in TMY format were available.

Table 5: Coordinates and elevation of locations

Location	Latitude	Longitude	Elevation
Thessaloniki	40,52°	22,97°	4 m
Athens	37,90°	23,73°	15 m
Andravida	37,92°	21,28°	12 m

The latitude, longitude and elevation of each location are presented in Table 5. The electricity rate for Greece, incorporating all taxes and energy prices, is 0,177 €/kWh [60]. The inclination is set at 45° according to the Greek regulation [61] and the inflation rate is set at 1%/year [40, 72]. The average daily hot water usage is 50 kg/day/person and the solar tank has a volume of 0,2 m^3.

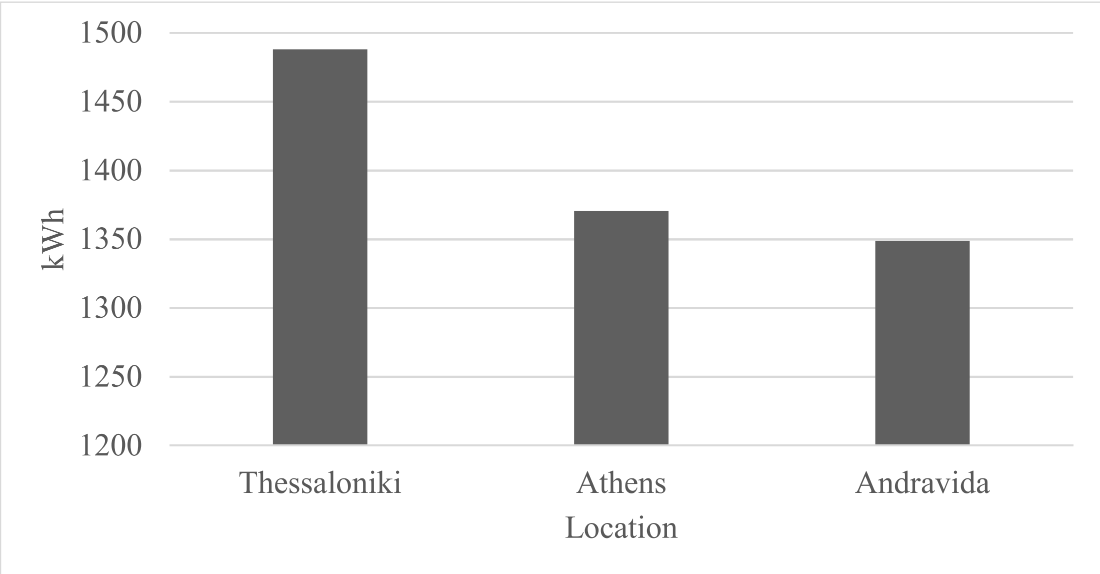

Figure 85: System energy

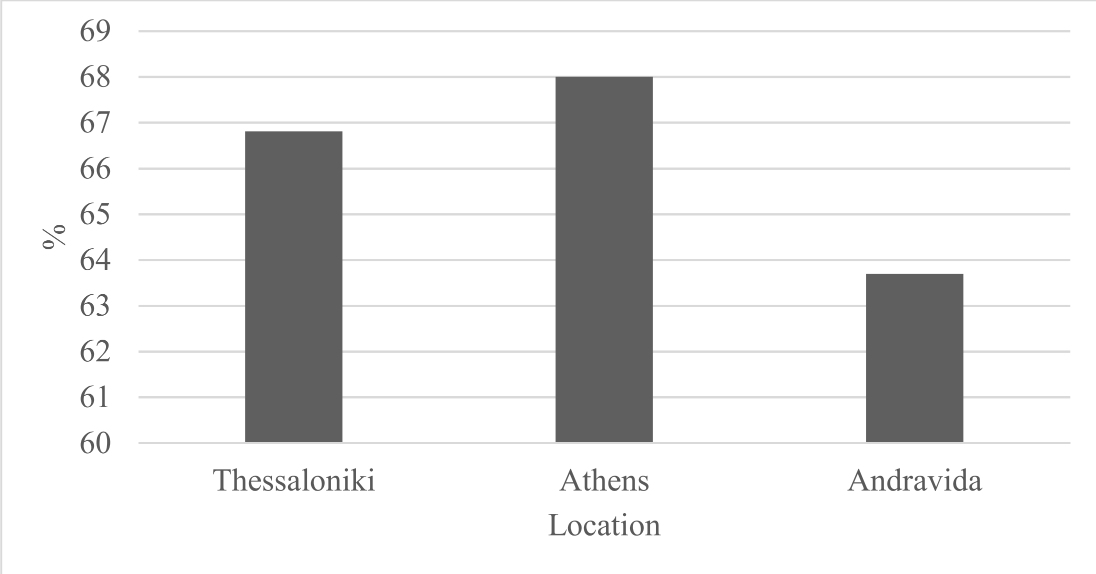

Figure 86: Solar fraction of the system

In Figure 85, it is evident that the highest amount of energy is produced in Thessaloniki with almost 1.488 kWh. While in Figure 86, it is shown that the solar fraction ranges from 64% to 68% with Athens presenting the highest one. Thessaloniki's energy demand of 2.227 kWh is higher than Athens' 2.015 kWh and Andravida's 2.117 kWh along with the fact that the domestic solar hot water system in Athens is taking more advantage of the solar radiation during the winter months.

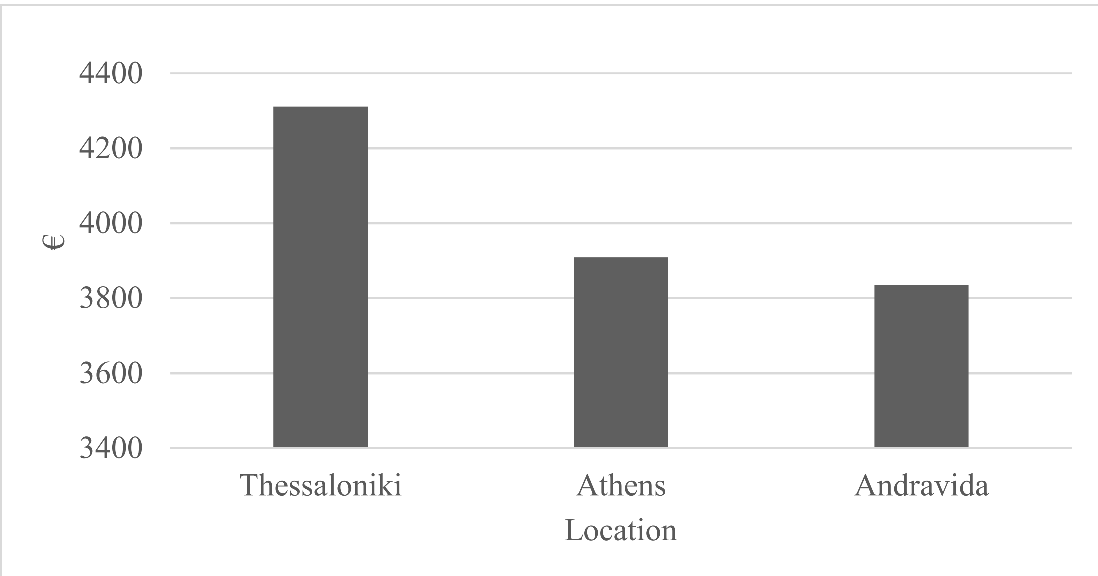

Figure 87: Net present value of the system

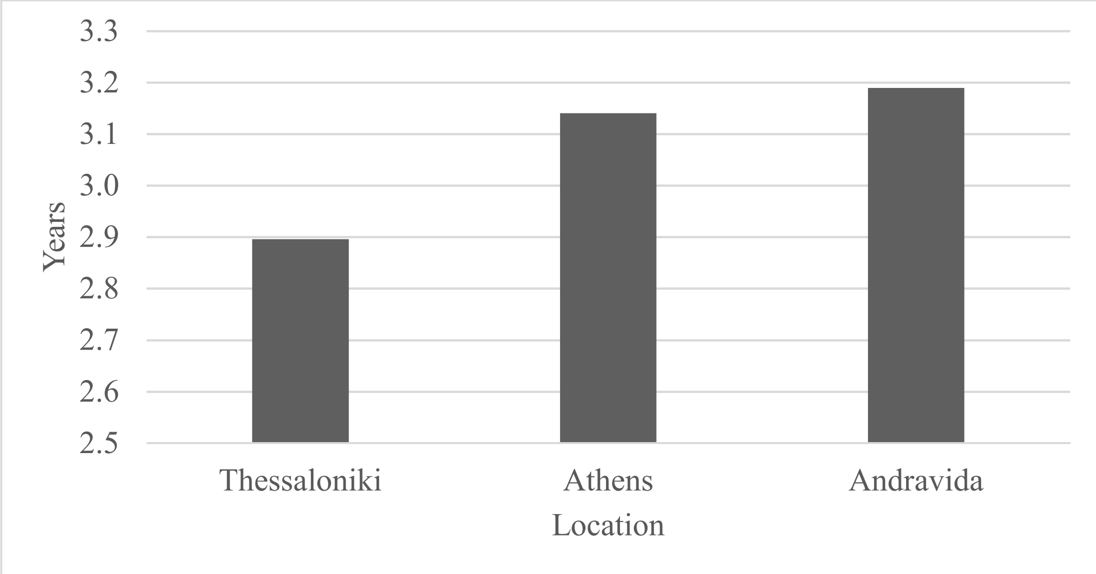

Figure 88: Payback period of the system

As presented in Figure 87, the highest net present value of the system is observed in Thessaloniki with almost 4.311€. That makes the project more economical feasible in this location because of more energy production. In Figure 88, it is apparent that Thessaloniki has the lowest payback period of 2,9 years which is in accordance with Figure 88 that means where the economic benefits are higher the payback period will be shorter.

Having concluded with the base case scenario for each location a number of parametric simulations is made in order to examine the influence of different inputs to system energy, solar fraction, net present value and payback period of the domestic solar hot water system. The first parametric analysis has as input the number of collectors taking into consideration 1, 2 and 3 collectors. In addition, the next parametric analysis has as input the solar tank volumes including 0,18 m^3, 0,2 m^3 and 0,22 m^3 while the other parametric has as input the inclinations for the solar collectors ranging from 25° to 55° in steps of 5°. Finally, the last parametric has as input the number of occupants considering 3, 4 and 5 occupants regarding their average daily hot water usage of 150 kg/day, 200 kg/day and 250 kg/day respectively.

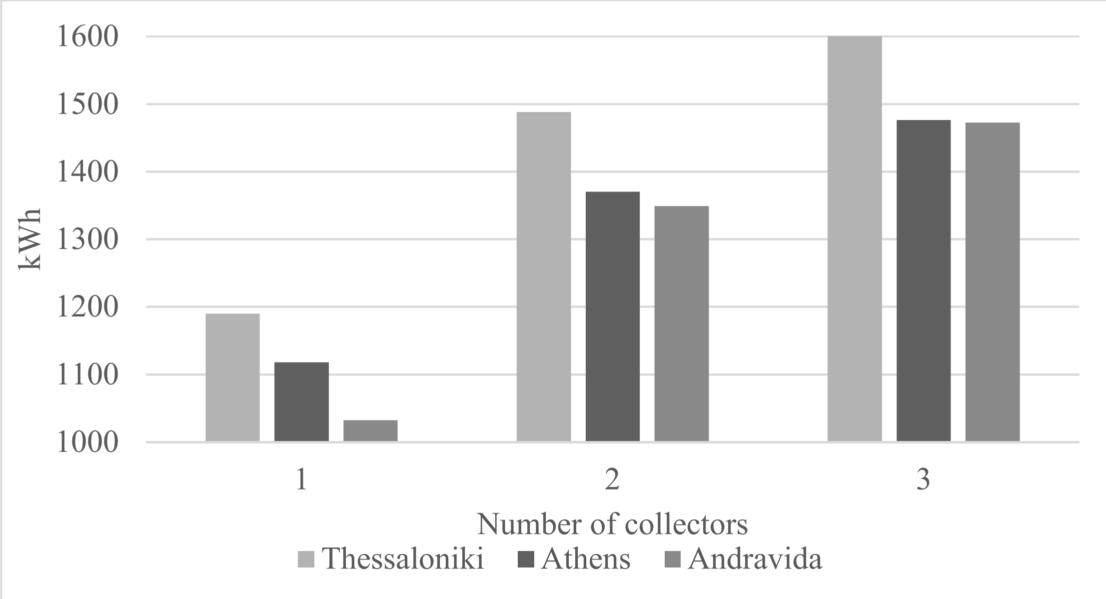

Figure 89: System energy for different collectors

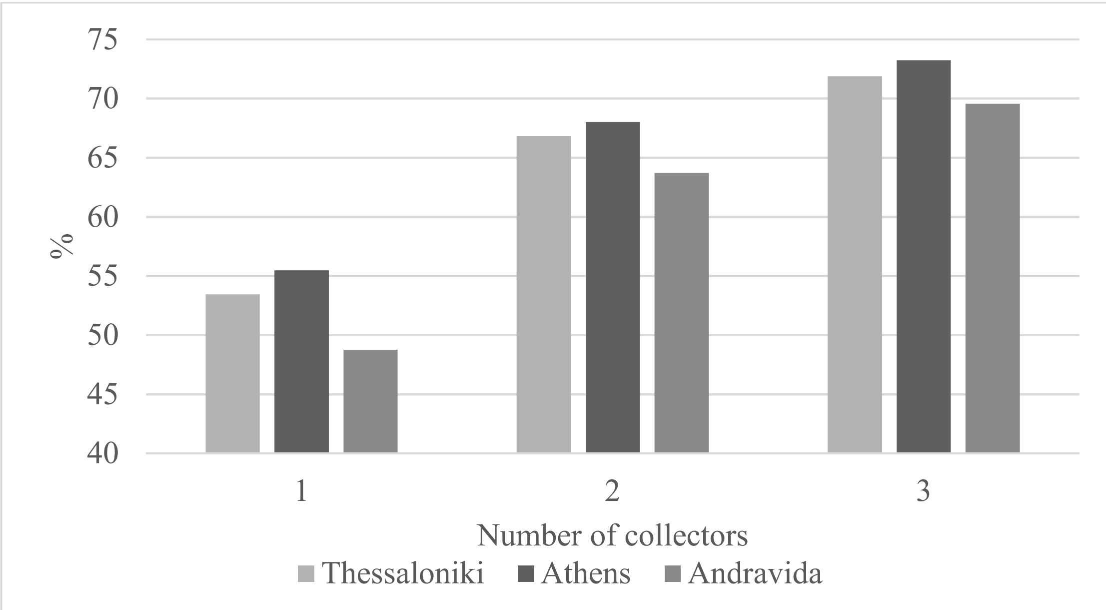

Figure 90: Solar fraction for different collectors

As presented in Figure 89, the system produces more energy as the number of collectors increases and Thessaloniki presents the highest values by 1.190 kWh, 1.488 kWh and 1.601 kWh. As shown in Figure 90, Athens presents the highest solar fraction in all cases with 55%, 68% and 73%. As the number of collectors increases, the solar fraction also does but not proportionately. Going from 1 collector to 2 collectors there is an increase of almost 12% but from 2 to 3 collectors the increase is 5%. During the summer months the energy demand is lower than the winter months.

By having more than 2 collectors solar fraction will have a small increase since the energy produced by the system may increase but the demand is less than the winter months.

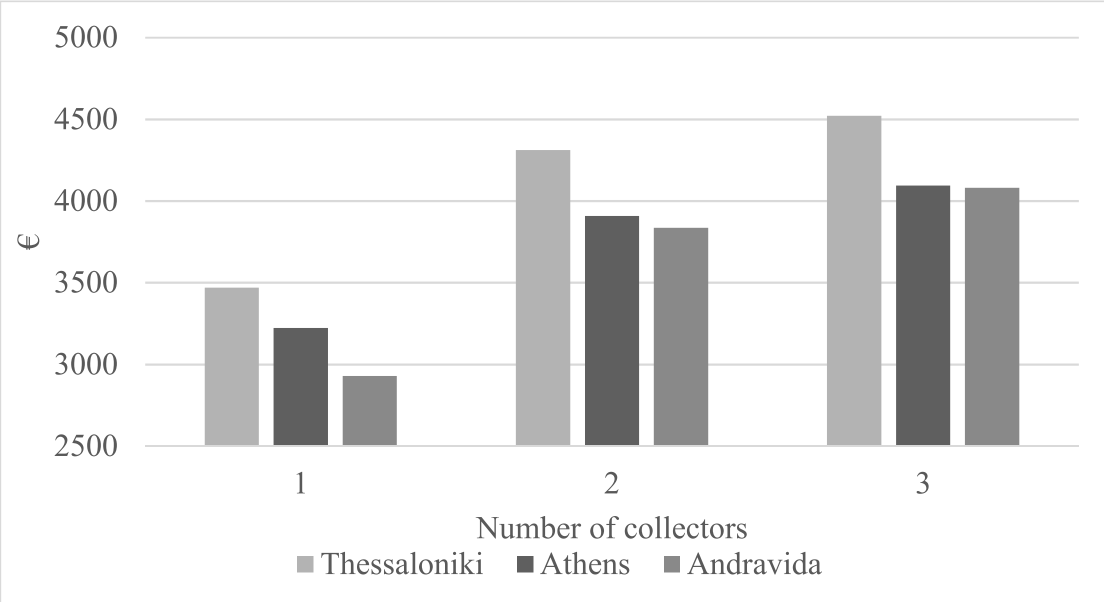

Figure 91: Net present value for different collectors

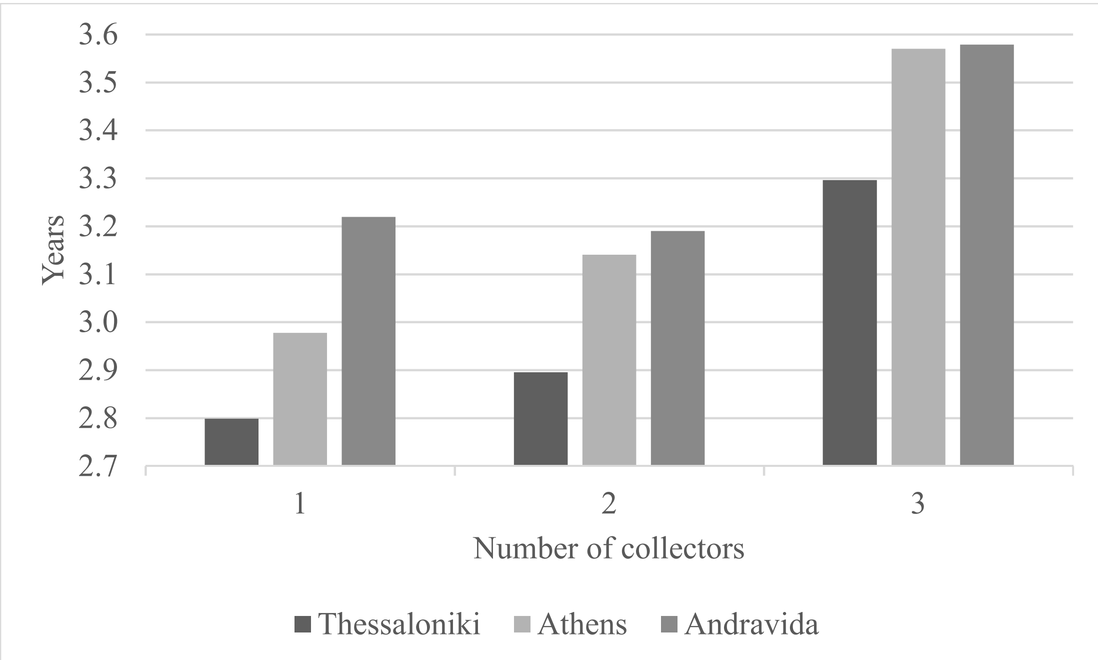

Figure 92: Payback period for different collectors

In Figure 91, the highest net present value is observed in Thessaloniki with 3.469€, 4.311€ and 4.520€ that makes the project more economical feasible in the case of 3 collectors where the most energy is produced. From Figure 92, it is apparent that the shortest payback period is noticed in Thessaloniki in all cases with 2,8 years, 2,9 years and 3,3 years which follows the rational of where the economic benefits are higher the payback period will be shorter.

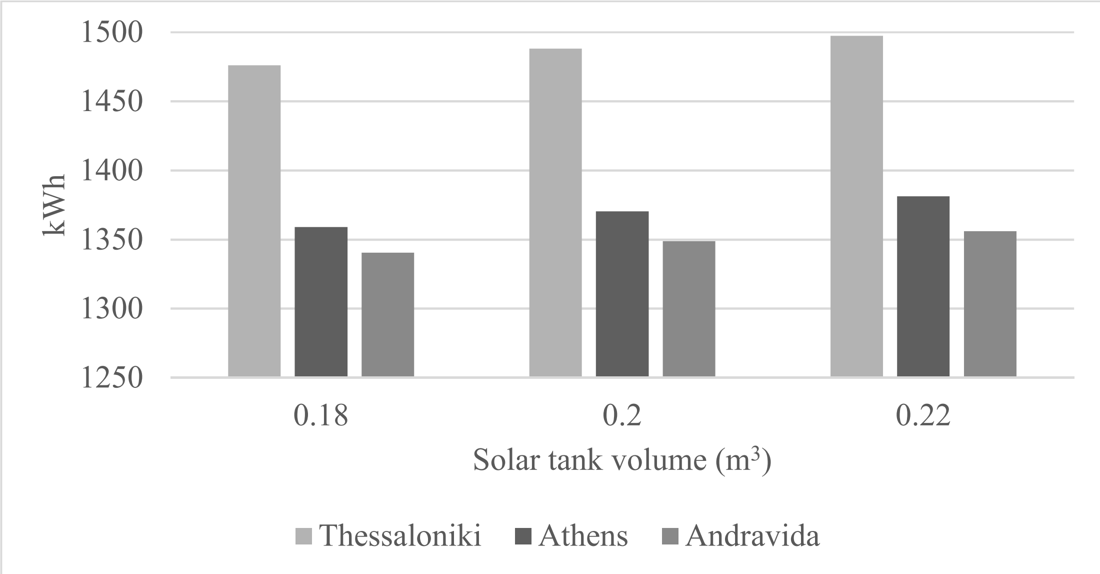

Figure 93: System energy for different solar tank volumes

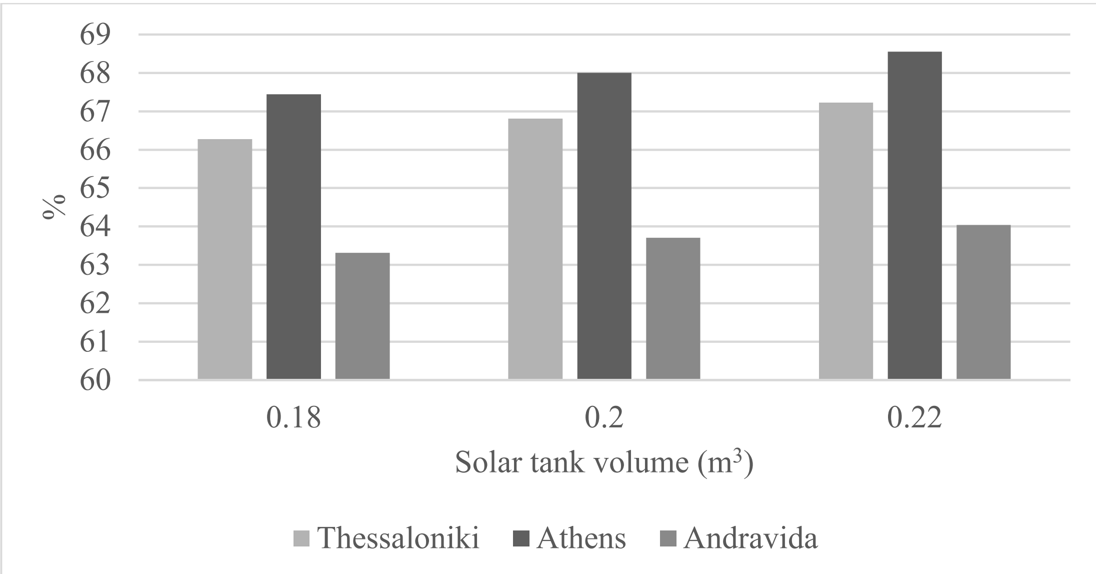

Figure 94: Solar fraction for different solar tank volumes

As shown in Figure 93, the energy produced by the system does not present large differences while the solar tank volume increases since the only thing that changes is the volume where water is stored. Thessaloniki presents the highest values by 1.476 kWh, 1.488 kWh and 1.497 kWh. As presented in Figure 94, Athens has the highest solar fractions with 67%, 68% and almost 69% and that the increase in the solar tank volumes does not influence coverage as much because the difference among them is 0,02 m^3 and the energy input of the domestic solar hot water system has small changes.

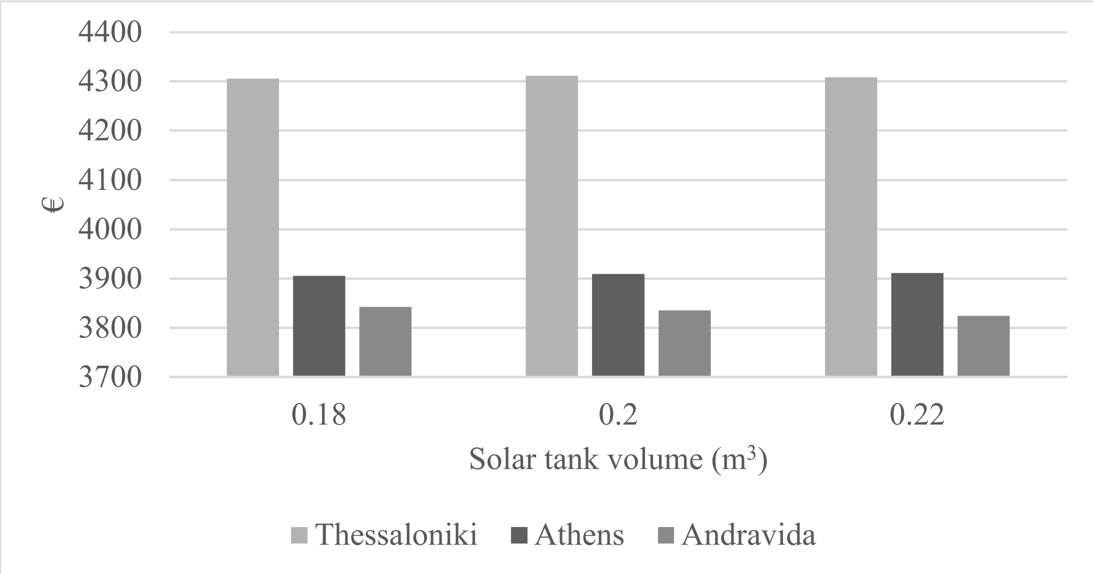

Figure 95: Net present value for different solar tank volumes

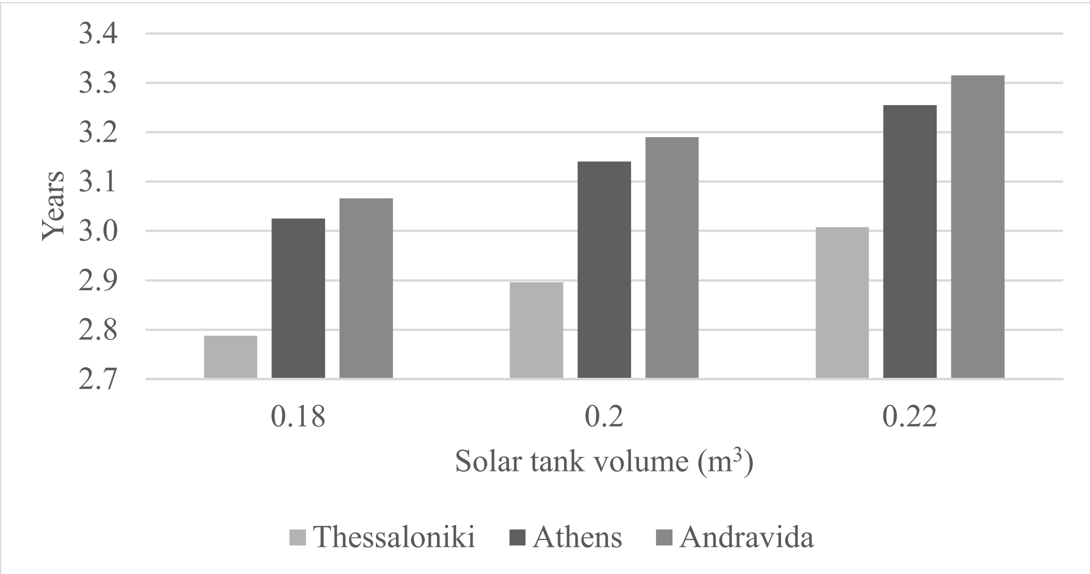

Figure 96: Payback period for different solar tank volumes

In Figure 95, the highest net present value is observed in Thessaloniki with small dissimilarities and that is why in Figure 96, Thessaloniki has also the lowest payback period without large differences.

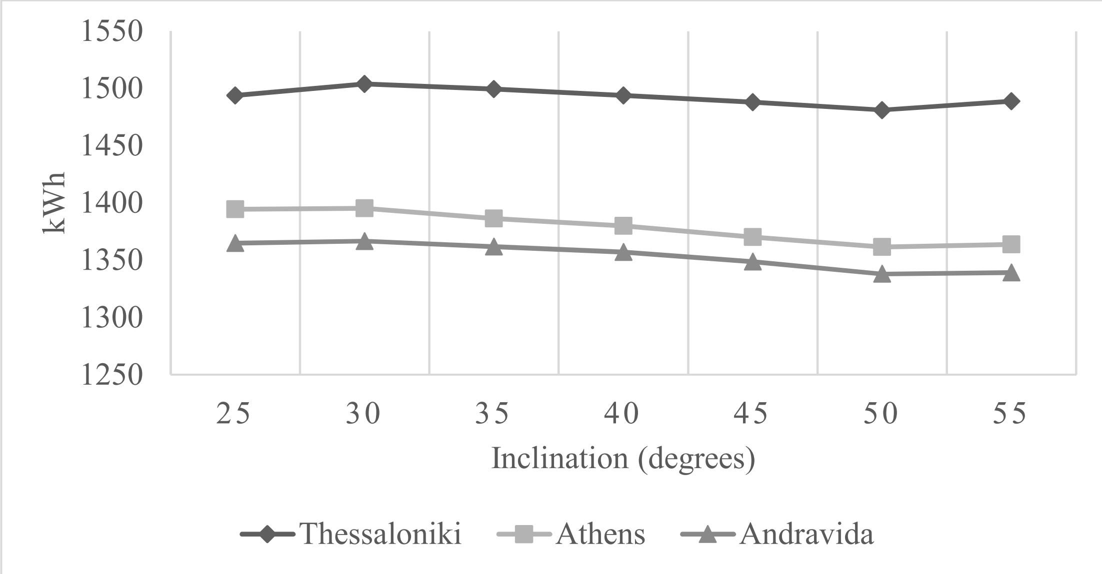

Figure 97: System energy for different inclinations

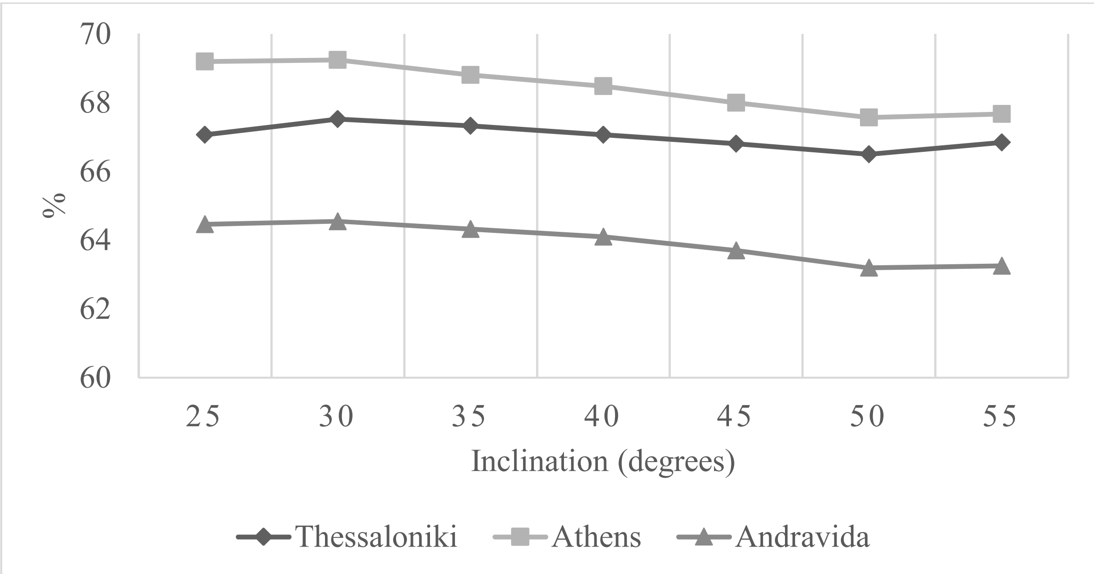

Figure 98: Solar fraction for different inclinations

In Figure 97, it is evident that the most energy is produced in Thessaloniki in the case of 30º with 1.504 kWh while in Figure 98 the solar fraction is higher in Athens in 30º with 69%. The domestic solar hot water system is producing more energy in Thessaloniki but the solar fraction is higher in Athens due to the fact that the energy demand in Athens is lower than it is in Thessaloniki. In all cases it is observed that after 30º the solar fraction and the system energy are decreasing. The small increase that exists after 50º is because of the solar gains that the system may have during some winter months.

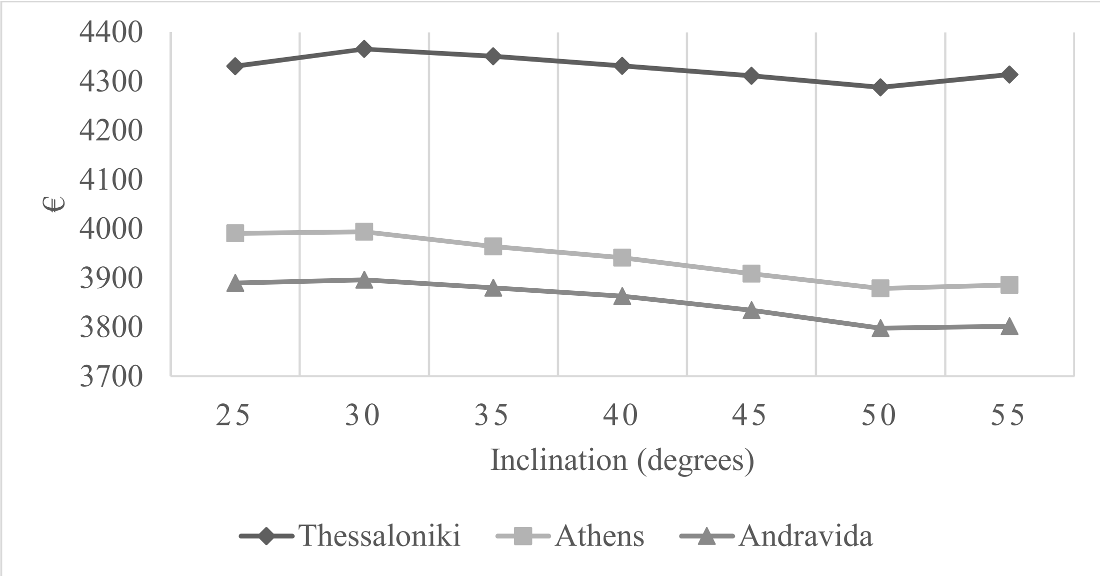

Figure 99: Net present value for different inclinations

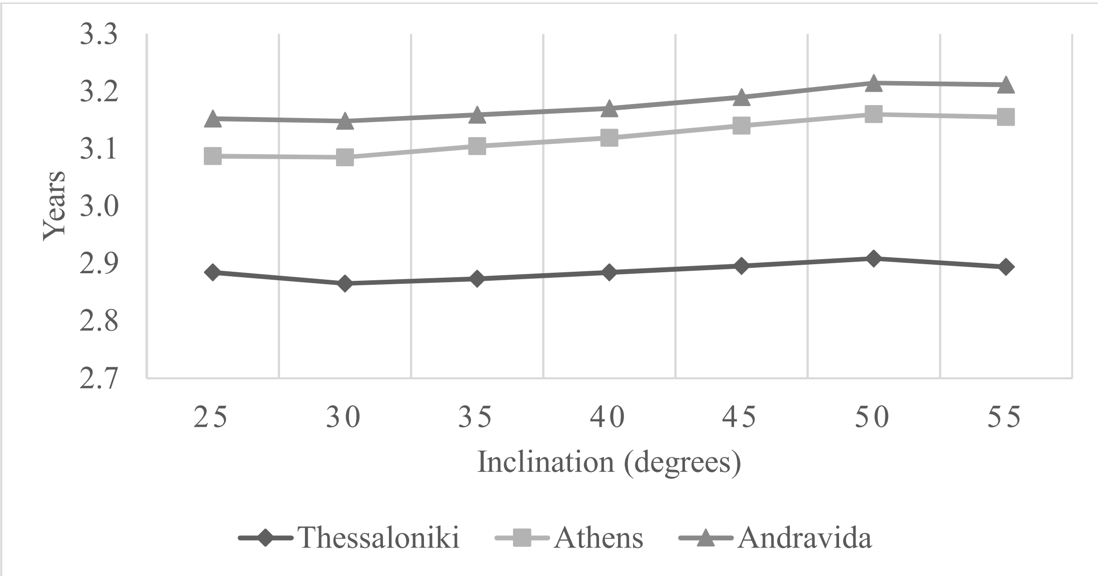

Figure 100: Payback period for different inclinations

In Figure 99, it is apparent that Thessaloniki presents the highest net present value noticed in 30º with 4.366€ making the project more economically feasible and in Figure 100, the lowest payback period is in Thessaloniki in the case of 30º with almost 2,8 years because of where the economic benefit is higher the payback period will be shorter.

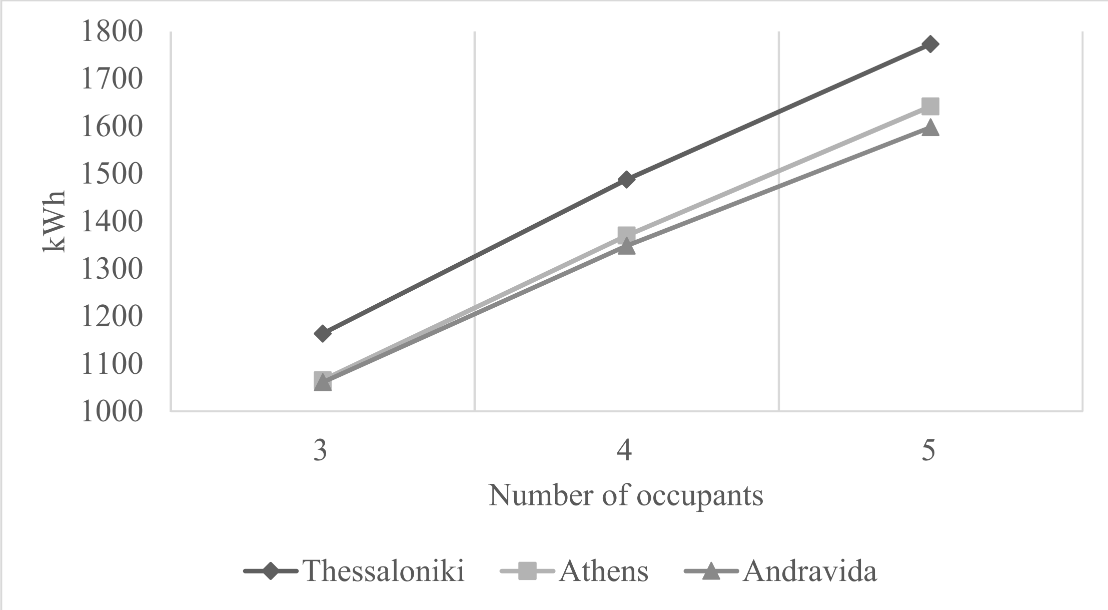

Figure 101: System energy for different occupants

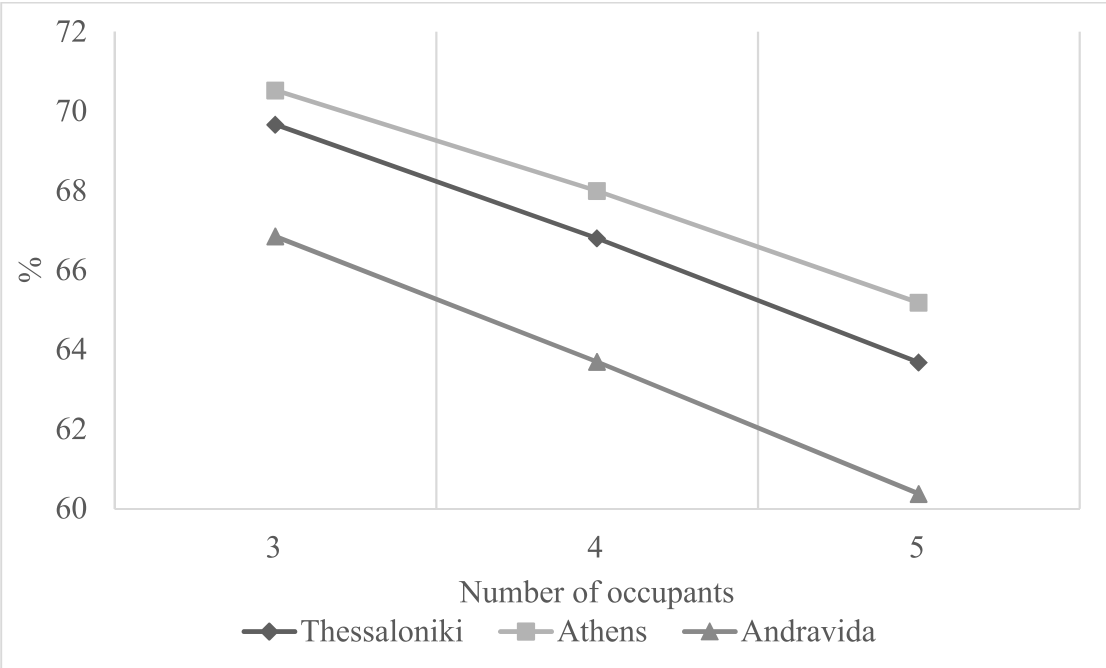

Figure 102: Solar fraction for different occupants

In Figure 101, it is evident that the most energy is produced in Thessaloniki for 5 occupants reaching 1.773 kWh. Some solar gains that the domestic solar hot water system has during summer months may not be used and are lost. As the number of occupants increases, their energy demand also increases and these extra solar gains that were not previously used are in favor to cover the occupants' needs. In Figure 102, solar fraction presents a decrease as the number of occupants increases. Athens has the highest solar fraction observed for 3 occupants being 71% and their average hot water usage equals to 150 kg/day. Despite the fact that the energy produced by the system is increasing, the total energy required is higher and as a result the solar fraction is diminishing.

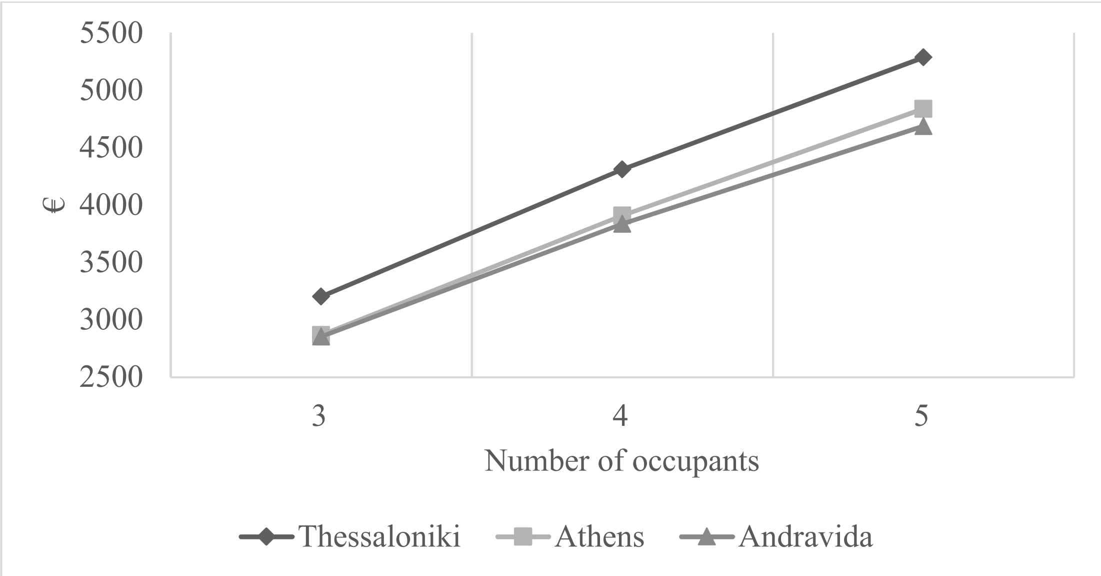

Figure 103: Net present value for different occupants

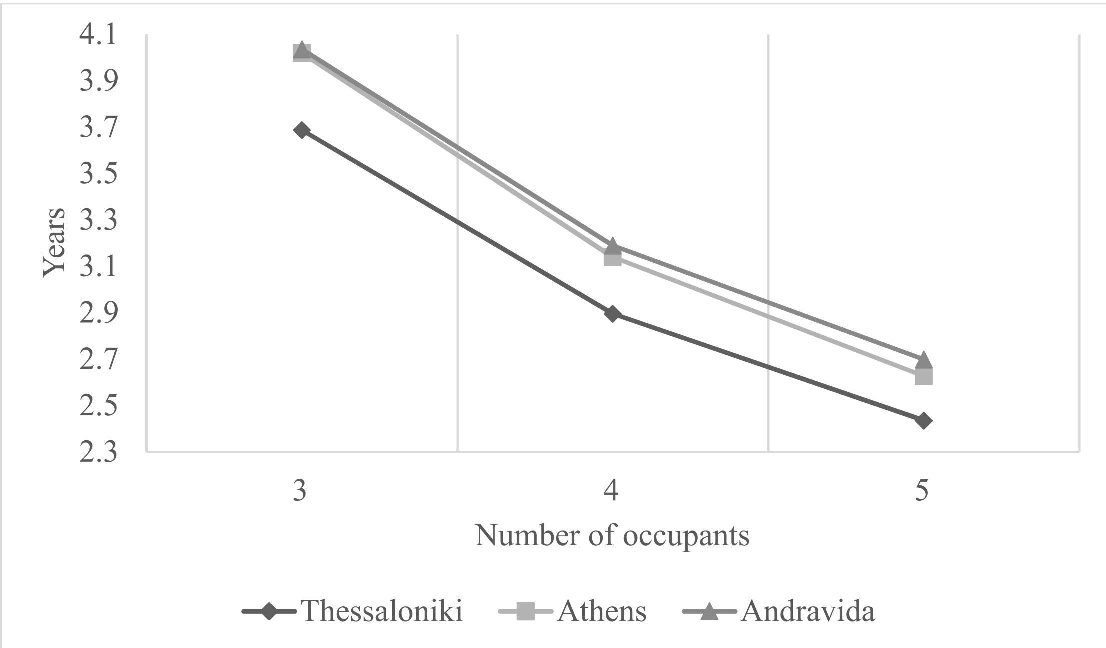

Figure 104: Payback period for different occupants

As shown in Figure 103, Thessaloniki has the highest net present value observed at 5.286€ for 5 occupants. This makes the project more economically feasible since the energy produced by the system in this case is the highest one. In Figure 104, the payback period is lowest in Thessaloniki for 5 occupants for 2,4 years which is in accordance to where there are large economic benefits, the payback period will be shorter.

It can be concluded that among the three locations of Greece, the base case scenario (4 occupants, collector area= 4 m^2, $F_R(\tau\alpha)$= 0,76, F_RU_L= 4,5 W/m^2 C, inclination= 45°) presents better performance in Thessaloniki in all aspects except for the solar fraction for which Athens has the highest one mainly due to less energy demand and its dry climate. In the first parametric analysis, the system produces more energy in Thessaloniki in the case of 3 collectors and has also the highest net present value along with the shortest payback period. Regarding solar fraction, Athens in the case of 3 collectors has the highest one and in general as the number of collectors increases, the solar fraction also increases but not with the same rate mainly because of the different energy demand during summer and winter months. Furthermore, the next parametric analysis showed that for system energy Thessaloniki presents the highest one in 0,22 m^3. Additionally, the parametric analysis having as input the inclination of the system showed that Thessaloniki had the best results in 30° regarding system energy, net present value and payback period. Athens presented the highest values for solar fraction in the case of 30°. Athens' dry climate compared to Thessaloniki's more humid one plays an important role in the absorption of solar radiation. After 50° there is a small increase because of some potential solar earnings the system may have during winter months. Finally, in the parametric analysis for the number of occupants, Thessaloniki presents the highest value for 5 occupants in system energy. As the number of occupants increases, the system takes advantage of the solar gains which in other cases (3 or 4 occupants) are lost and raises its energy production. Athens has the highest solar fraction for 3 occupants. Even if the domestic solar hot water system produces more energy for 5 occupants, the energy required for them remains higher. It is reasonable since the less the number of people and their average daily hot water usage of 150 kg/day, the domestic solar hot water system can provide more coverage for their needs. Thessaloniki presents the highest net present value and the shortest payback period for 5 occupants following the essential of where the economic benefits are higher, the shorter is the payback period of the initial investment as electricity replacement.

Having calculated the solar fraction for various household types in three locations in Greece, a rough estimation of the total energy conservation that the use of solar thermal systems has in Greece is performed. According to the Hellenic Statistical Authority [66] the average size of a typical household consists of 3 occupants. The average solar fraction of the locations that corresponds to this number of occupants is 67,6% which means that the amount of energy saved annually from a domestic solar hot water system similar to the base case scenario results to 1.370 kWh per system. Taking into consideration the total glazed area of the country and the residential energy consumption [63], the total energy conservation for all systems in Greece during the last 11 years is estimated.

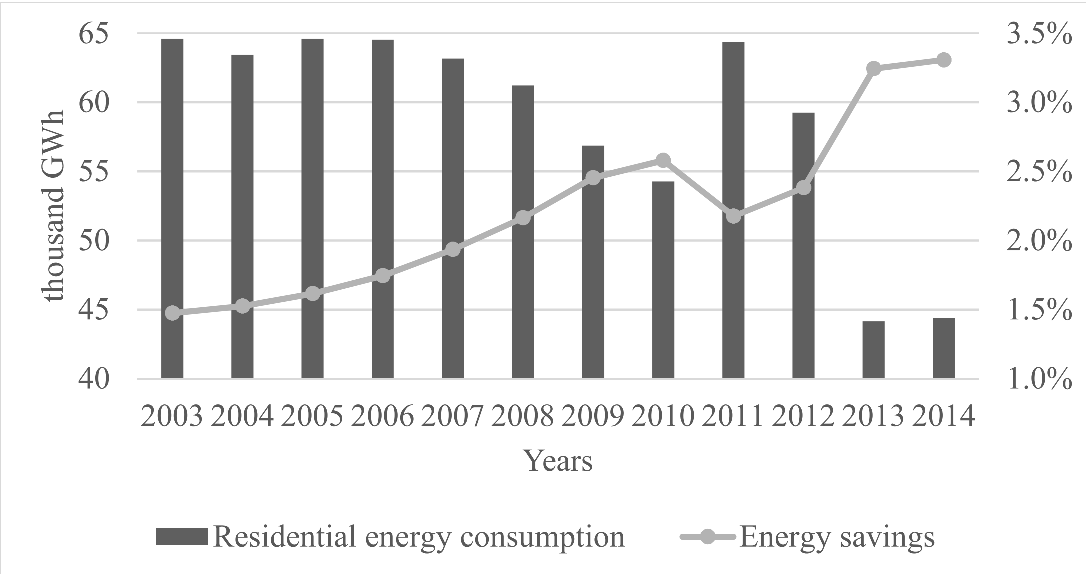

Figure 105: Total energy conservation

As presented in Figure 105, the total energy conservation increased during the last years as more systems were installed. It started with 952 GWh in 2003, it remained steady from 2009 to 2012 due to economic crisis and resulted to 1.468 GWh in 2014. There is an increase of 54% from 2003 to 2014. Since 2005, energy consumption in the residential sector has started to decrease except for some increases like 2011 and 2012. The reduction was influenced by economic performance, lower heat consumption due to better climatic conditions, more efficient electrical appliances and heating systems. In 2003, the potential energy savings deriving from the domestic solar hot water systems accounted for 1,5% of the total residential energy consumption. These savings reached to 3,3% of the total residential energy consumption in Greece in 2014.

In order to estimate the emissions reduction of GHG because of the domestic solar hot water systems usage, the emission factors for Greece per kWh of electricity generated were taken into consideration [64].

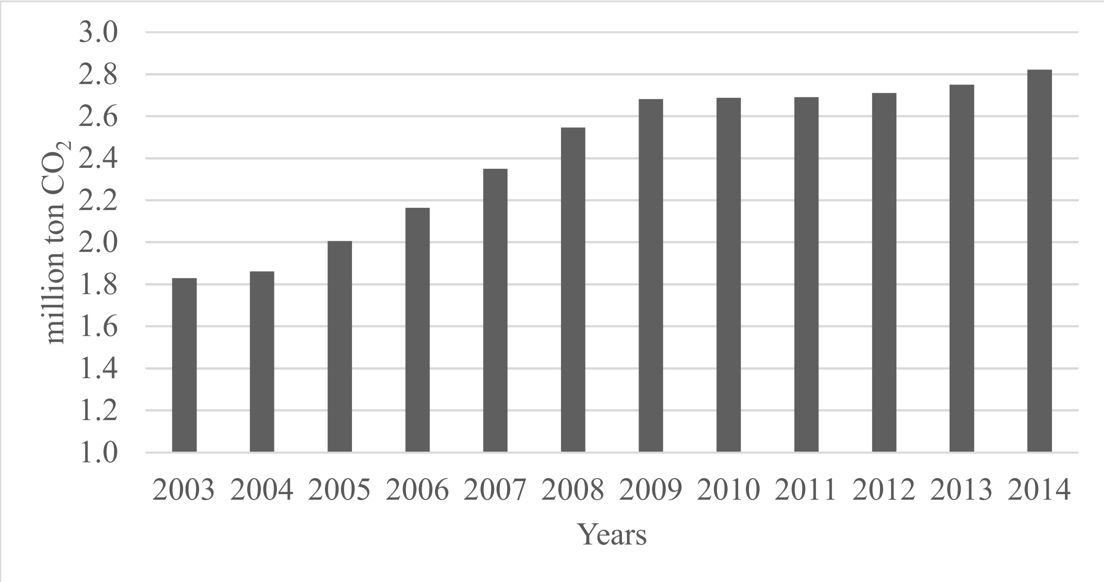

Figure 106: Tons of CO_2 saved

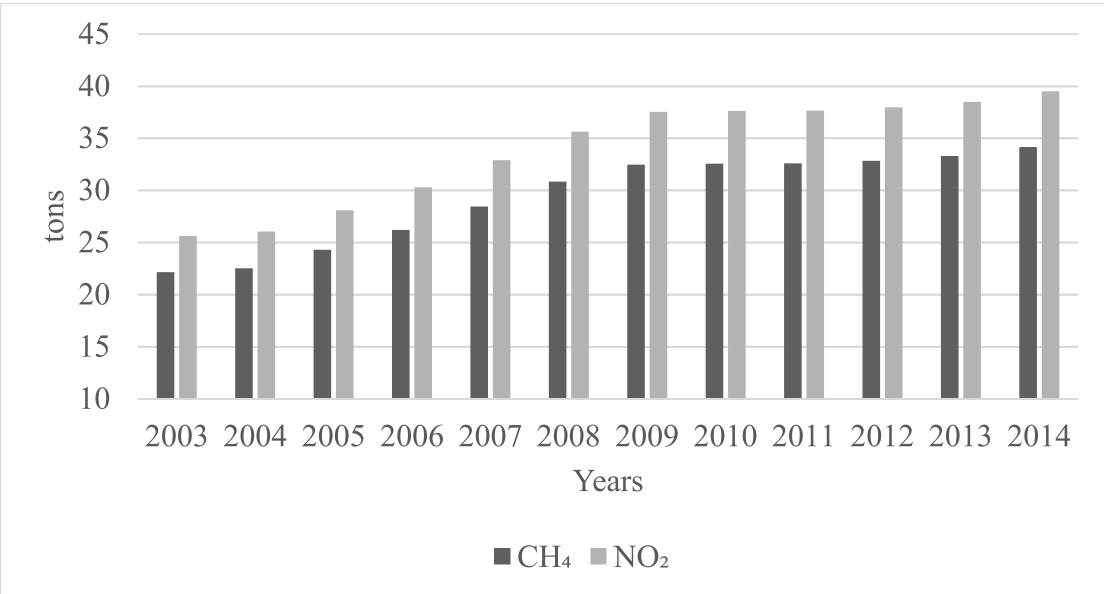

Figure 107: Tons of CH_4 and NO_2 saved

As presented in Figure 106, there was a steady increase of 55% for million tons of CO_2 saved by the domestic solar hot water systems usage from 2003 to 2014. It started with 1,8 million tons in 2003 and reached 2,8 million tons in 2014. The same happened with CH_4 and NO_2, as presented in Figure 107, that started with 22 and

25,61 tons in 2003 and reached 34 and 39,5 tons in 2014 respectively with their increase of saved tons being 54%.

4.4. ITALY

The locations examined for Italy are the metropolitan areas of Torino in North West Italy, Pisa in Northern Italy, Naples in Central Italy, Brindisi in Eastern Italy and Palermo in Southern Italy in order to cover all the different climatic conditions and for which full meteorological data in TMY format were available.

Table 6: Coordinates and elevation of locations

Location	Latitude	Longitude	Elevation
Torino	45,22°	7,65°	287 m
Pisa	43,68°	10,38°	1 m
Naples	40,85°	14,3°	72 m
Brindisi	40,65°	17,95°	10 m
Palermo	38,18°	13,1°	34 m

The latitude, longitude and elevation of each location are presented in Table 6. The electricity rate for Italy, incorporating all taxes and energy prices, is 0,243 €/kWh [60]. The inclination is set at 40° and the inflation rate is set at 1%/year [40, 72]. The average daily hot water usage is 50 kg/day/person and the solar tank has a volume of 0,2 m^3.

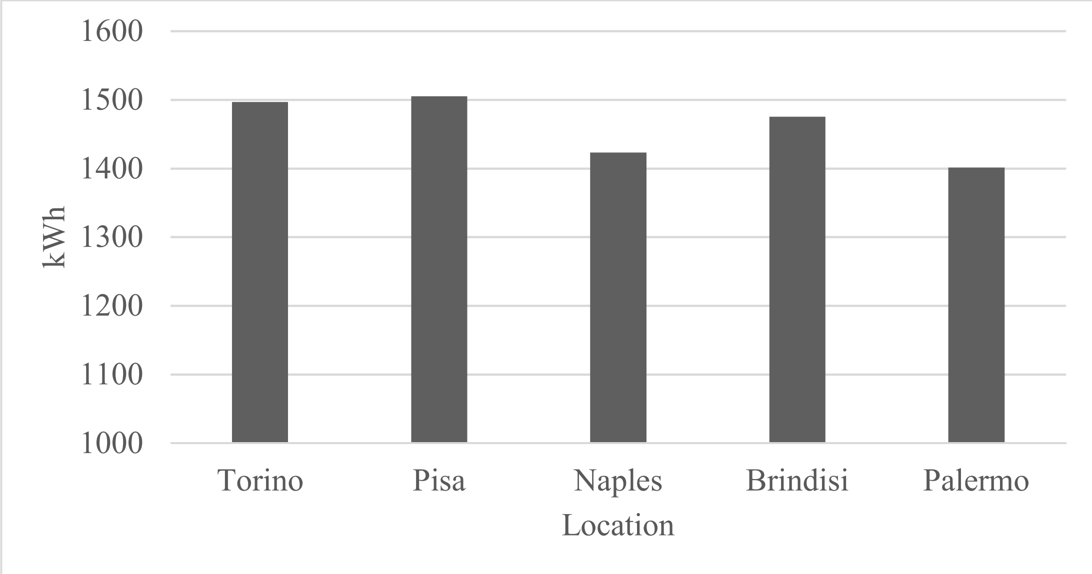

Figure 108: System energy

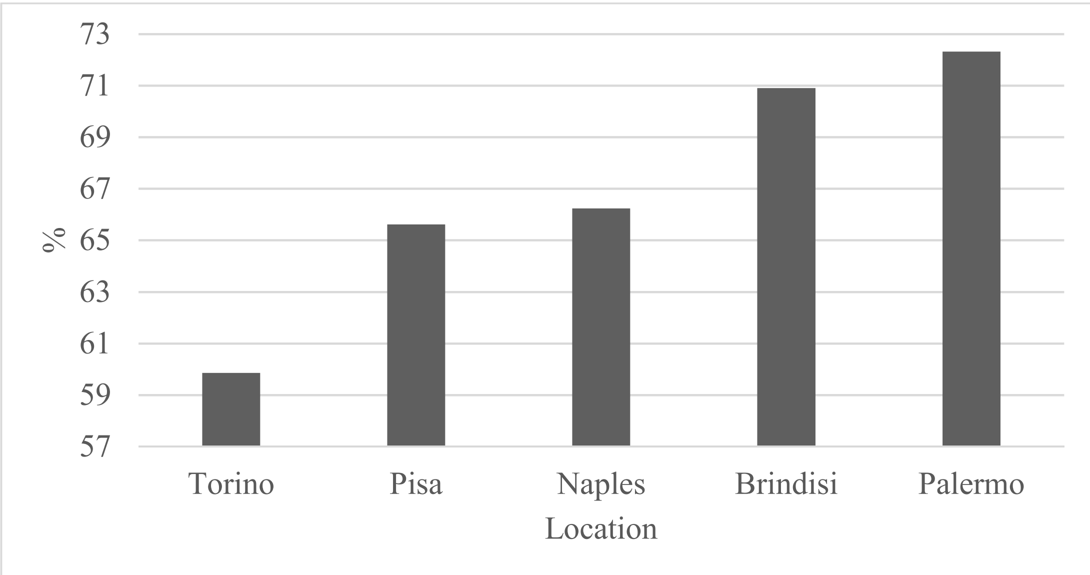

Figure 109: Solar fraction of the system

In Figure 108, it is evident that the highest amount of energy is produced in Pisa with almost 1.505 kWh. In Figure 109, it is shown that the solar fraction ranges from 60% to 72% with Palermo presenting the highest one. This shows that the energy produced by the domestic solar hot water system in Palermo is enough to cover 72% of the total energy demand compared to the other locations' demand. Palermo's energy demand of 1.937 kWh is lower compared to torino's 2.500 kWh, Pisa's 2.294 kWh, Naples' 2.148 and Brindisi's 2.080 kWh.

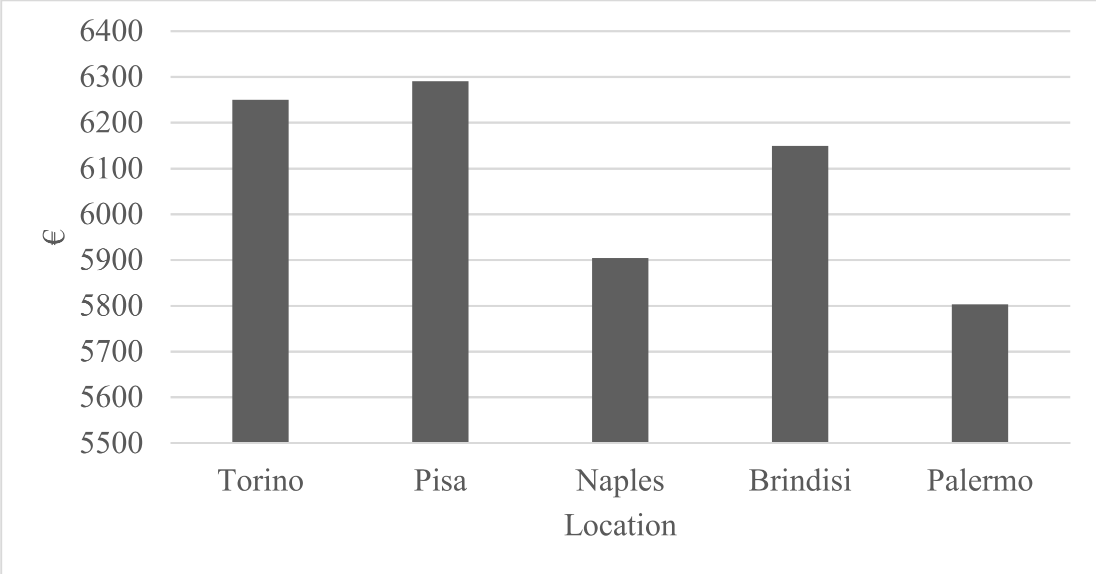

Figure 110: Net present value of the system

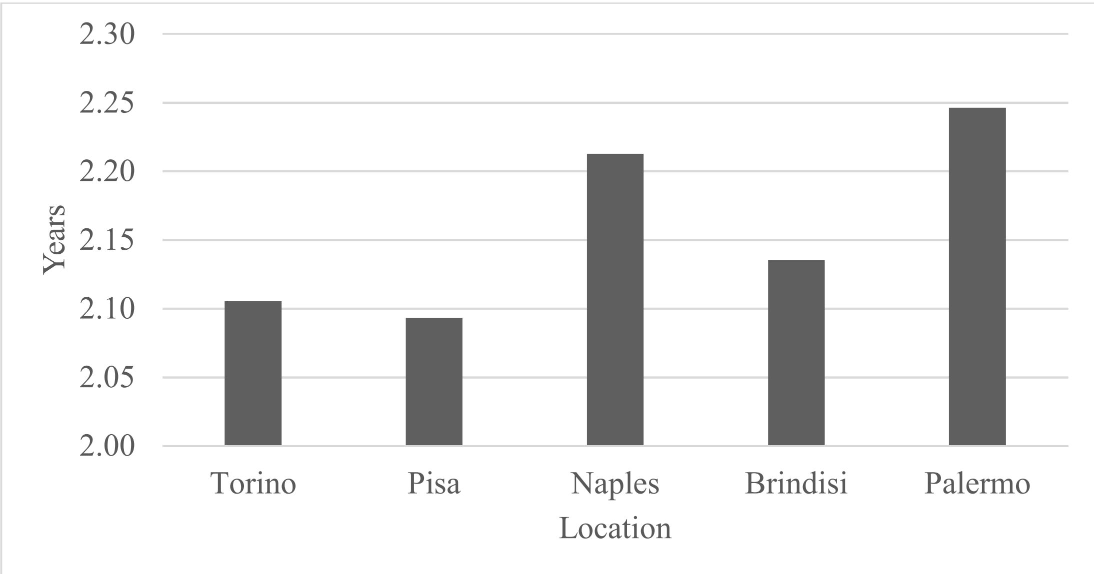

Figure 111: Payback period of the system

As presented in Figure 110, the highest net present value of the system is observed in Pisa with almost 6.291€. That makes the project more economical feasible in this location because of more energy production. In Figure 111, it is apparent that Pisa has the lowest payback period that means where the economic benefits are higher the payback period will be shorter.

Having concluded with the base case scenario for each location a number of parametric simulations is made in order to examine the influence of different inputs to system energy, solar fraction, net present value and payback period of the domestic solar hot water system. The first parametric analysis has as input the number of collectors taking into consideration 1, 2 and 3 collectors. In addition, the next parametric analysis has as input the solar tank volumes including 0,18 m^3, 0,2 m^3 and 0,22 m^3 while the other parametric has as input the inclinations for the solar collectors ranging from 25º to 55º in steps of 5º. Finally, the last parametric has as input the number of occupants considering 3, 4 and 5 occupants regarding their average daily hot water usage of 150 kg/day, 200 kg/day and 250 kg/day respectively.

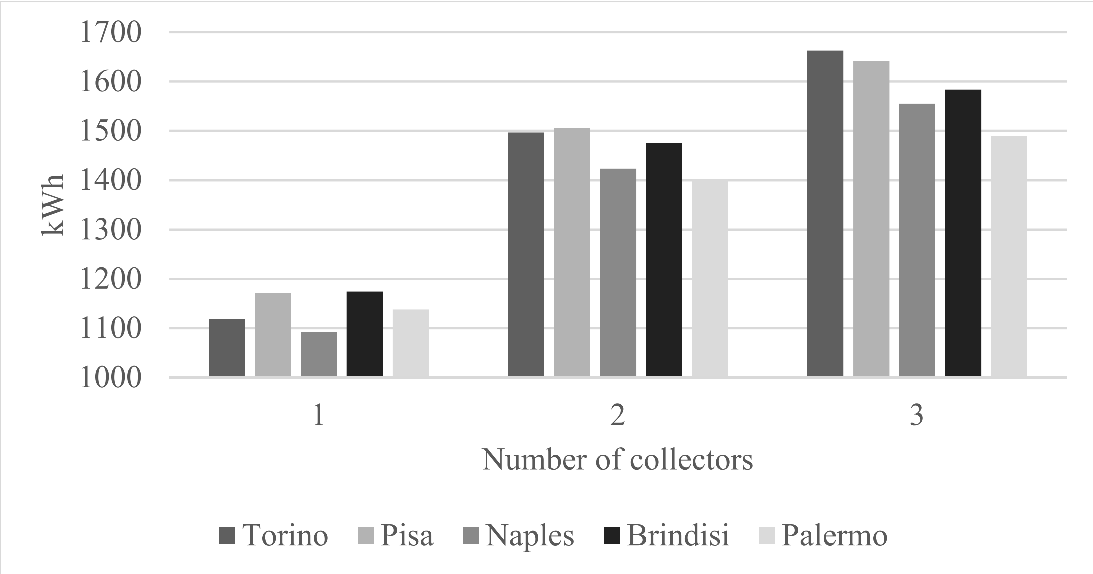

Figure 112: System energy for different collectors

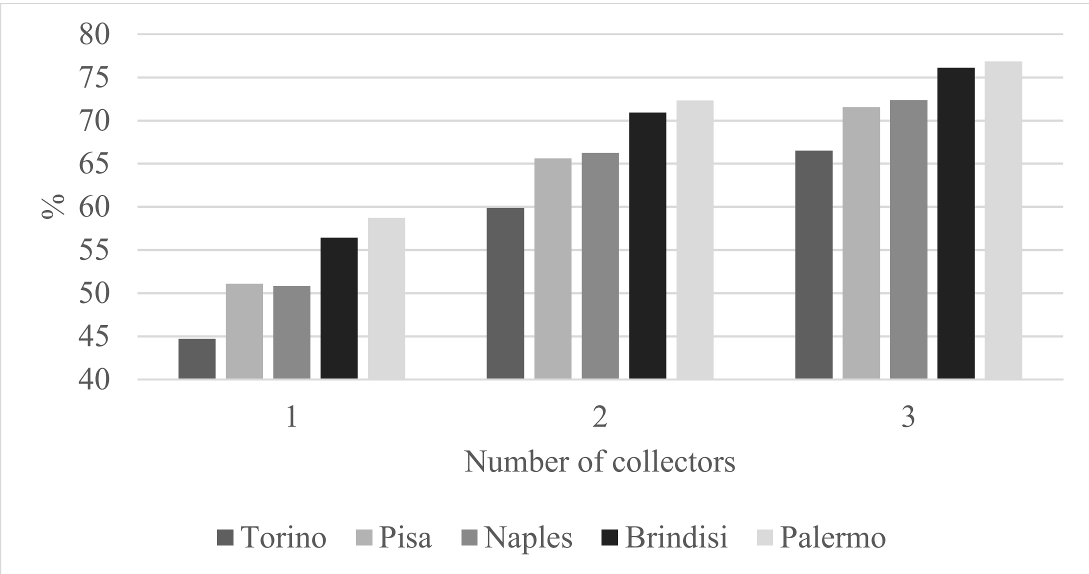

Figure 113: Solar fraction for different collectors

As presented in Figure 112, the system produces more energy as the number of collectors increases and Torino presents the highest value by 1.663 kWh in the case of 3 collectors. As shown in Figure 113, Palermo presents the highest solar fraction in all cases with 59%, 72% and 77%. As the number of collectors increases, the solar fraction also does but not proportionately. Going from 1 collector to 2 collectors there is an increase of almost 13% but from 2 to 3 collectors the increase is 5%. During the summer months the energy demand is lower than the winter months. By having more than 2 collectors solar fraction will have a small increase since the energy produced by the system may increase but the demand is less than the winter months.

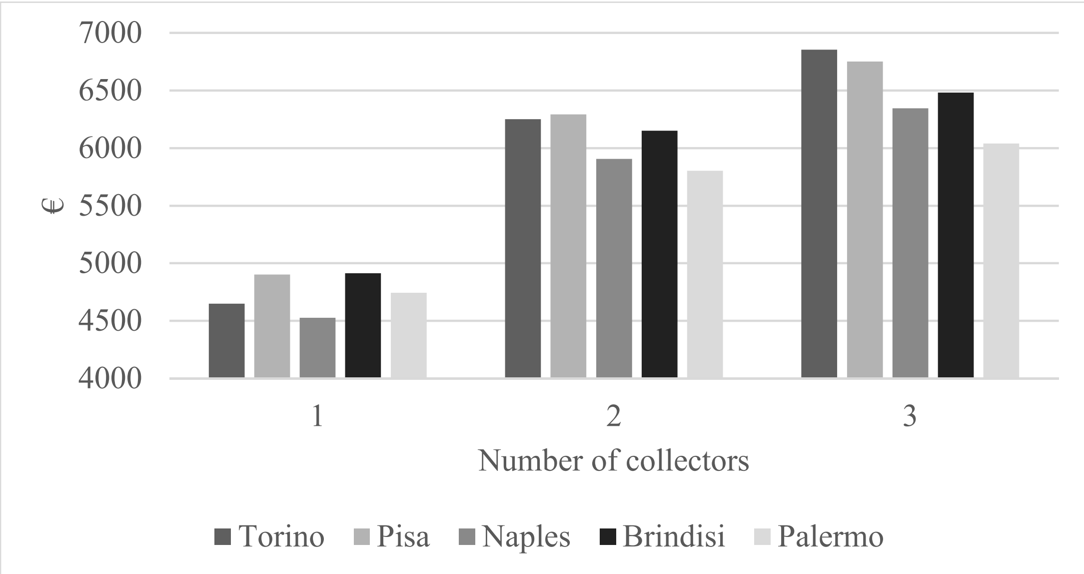

Figure 114: Net present value for different collectors

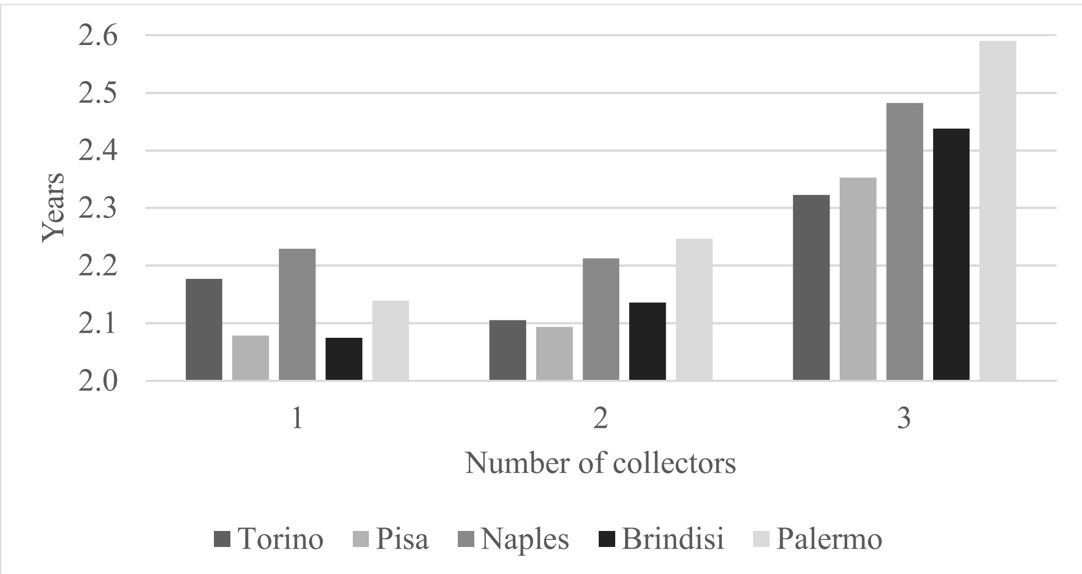

Figure 115: Payback period for different collectors

In Figure 114, the highest net present value is observed in Torino with 6.853€ that makes the project more economical feasible in the case of 3 collectors where the most energy is produced. From Figure 115, it is apparent that the shortest payback period is noticed in Pisa and Brindisi in the case of 1 collector with 2 years. In the case of 3 collectors, Torino presents the shortest payback period with 2,3 years following the rational of where the economic benefit is higher, the payback period is shorter.

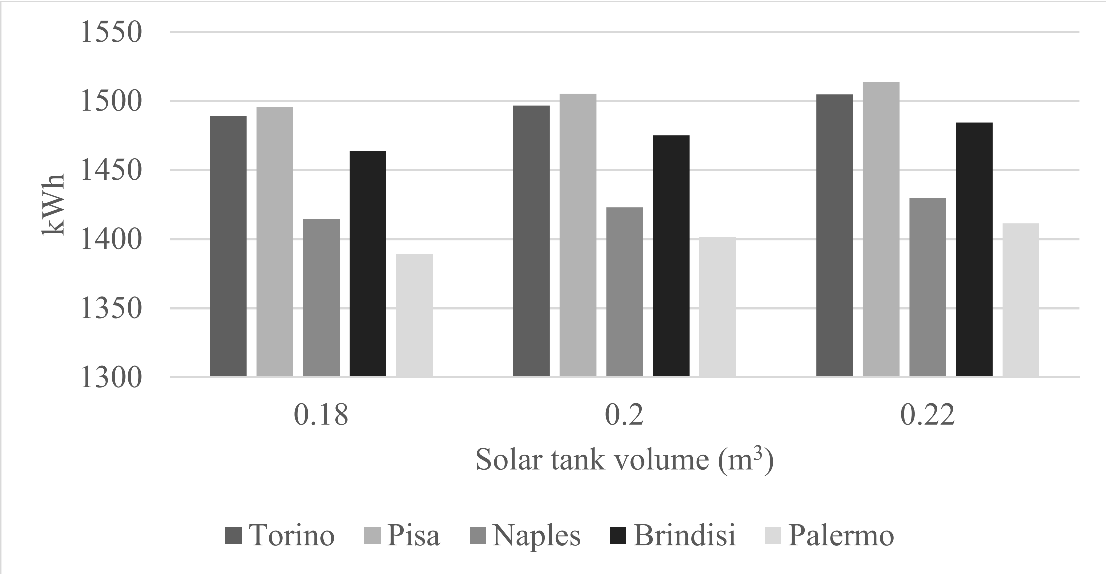

Figure 116: System energy for different solar tank volumes

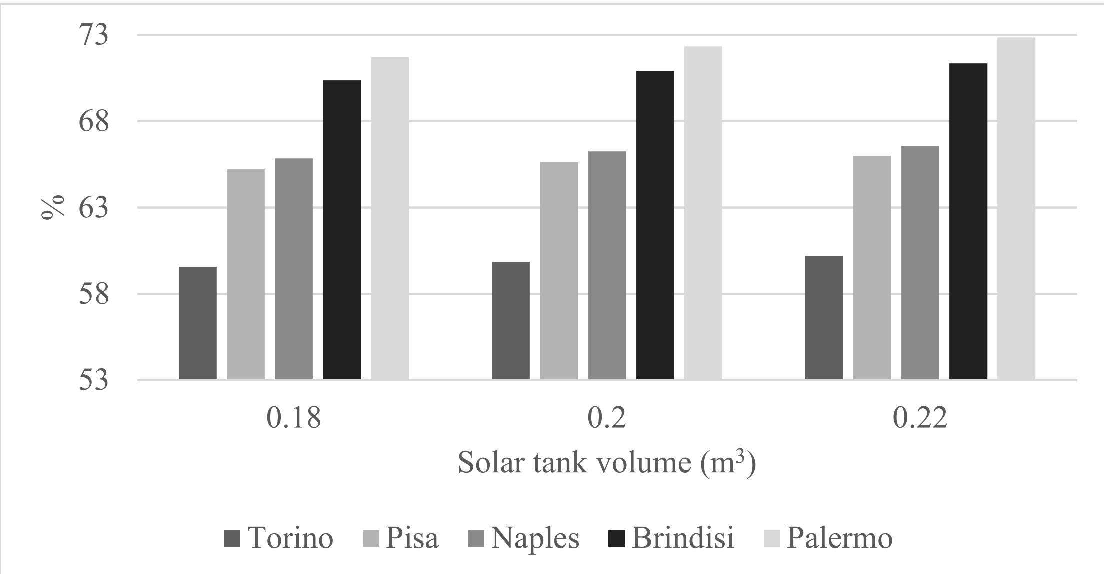

Figure 117: Solar fraction for different solar tank volumes

As shown in Figure 116, the energy produced by the system does not present large differences while the solar tank volume increases since the only thing that changes is the volume where water is stored. Pisa presents the highest values. As presented in Figure 117, Palermo has the highest solar fractions ranging from 71% to 73% and that the increase in the solar tank volumes does not influence coverage as much because the difference among them is 0,02 m^3 and the energy input of the domestic solar hot water system has small changes.

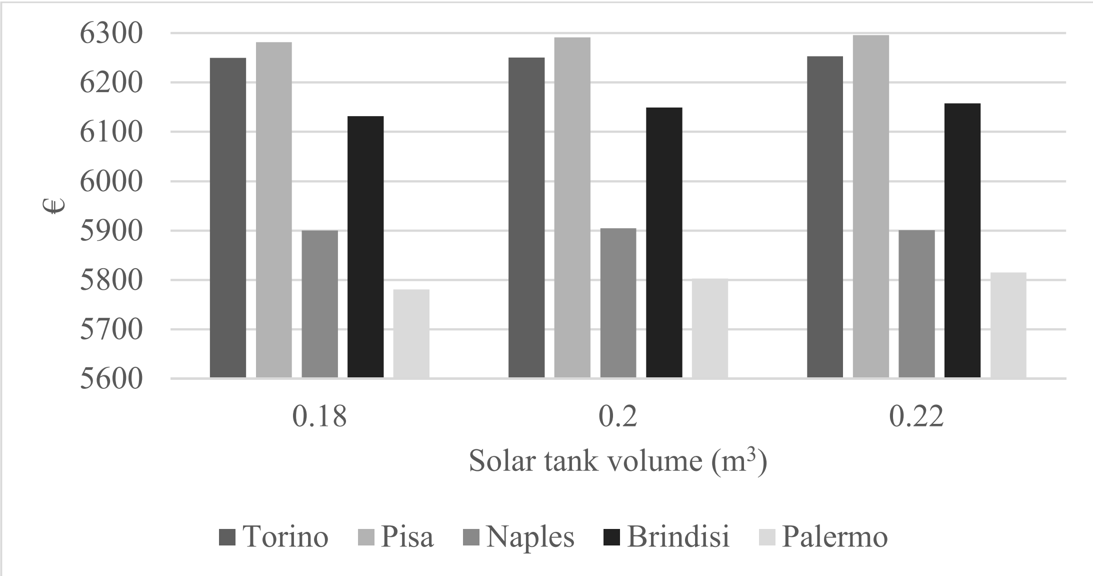

Figure 118: Net present value for different solar tank volumes

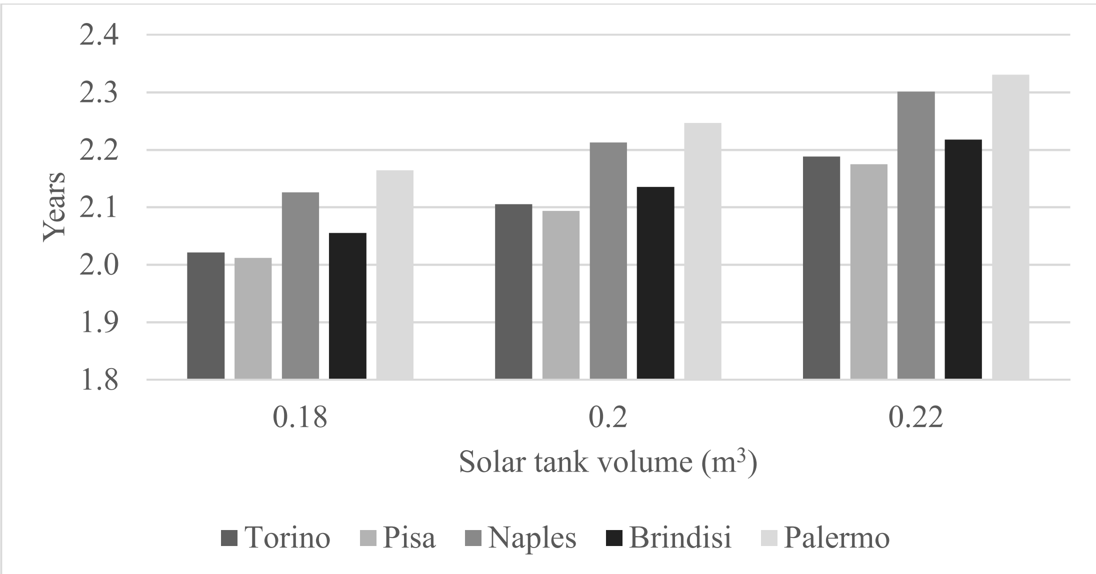

Figure 119: Payback period for different solar tank volumes

In Figure 118, the highest net present value is observed in Pisa with small dissimilarities and that is why in Figure 119, Pisa has also the lowest payback period without large differences.

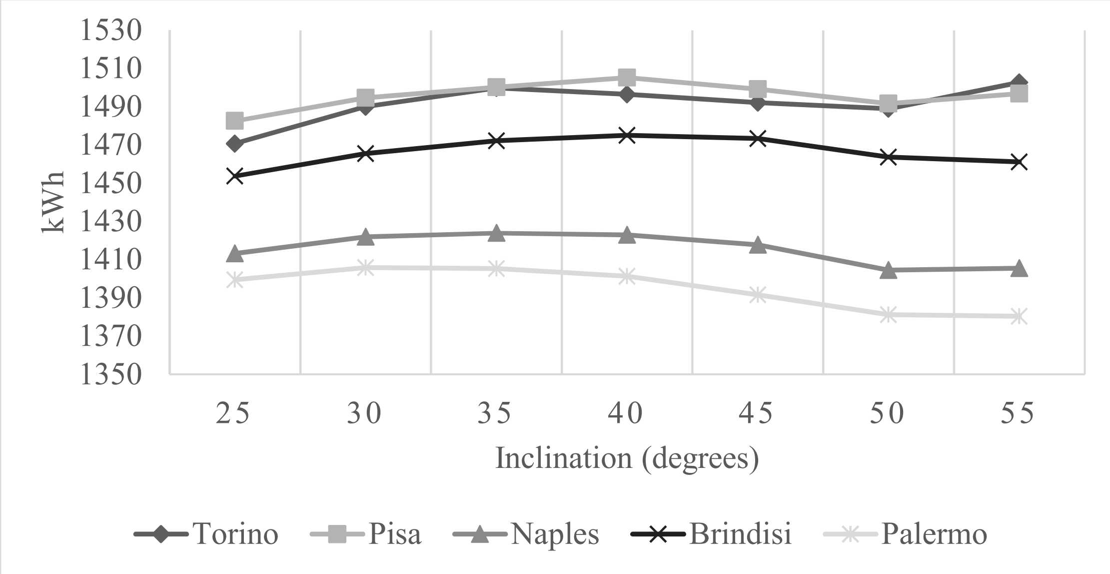

Figure 120: System energy for different inclinations

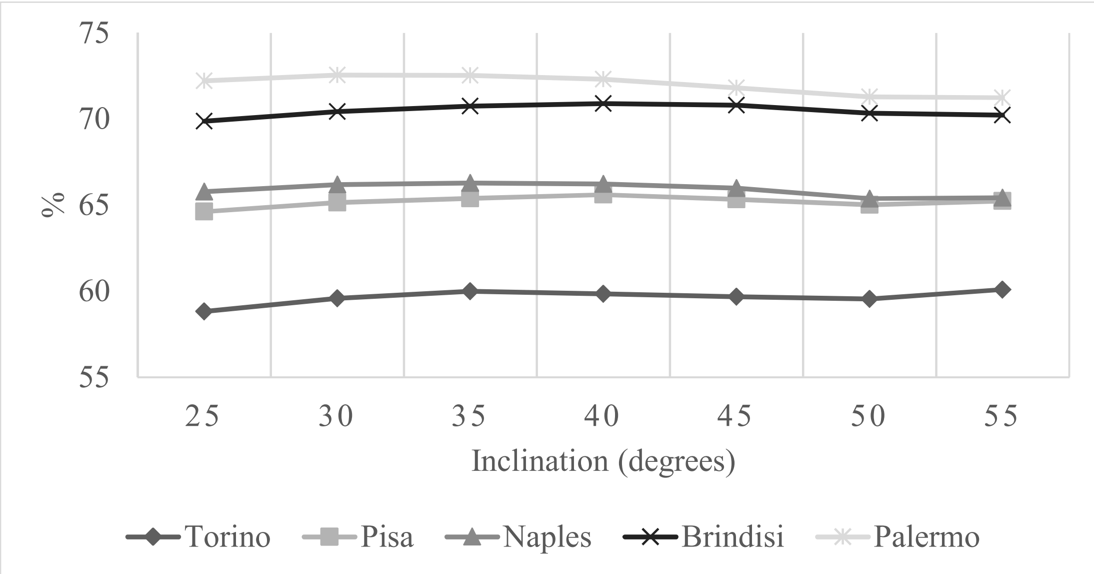

Figure 121: Solar fraction for different inclinations

In Figure 120, it is apparent that the most energy is produced in Pisa in the case of 40° with 1.505 kWh while in Figure 121 the solar fraction is higher in Palermo in 30° and 35° with 72,5%. The domestic solar hot water system is producing more energy in Pisa but the solar fraction is higher in Palermo due to the fact that the energy demand in Palermo is lower than it is in Pisa. In all cases it is observed that after 40° the solar fraction and the system energy are decreasing. The small increase that exists after 50° is because of the solar gains that the system may have during some winter months.

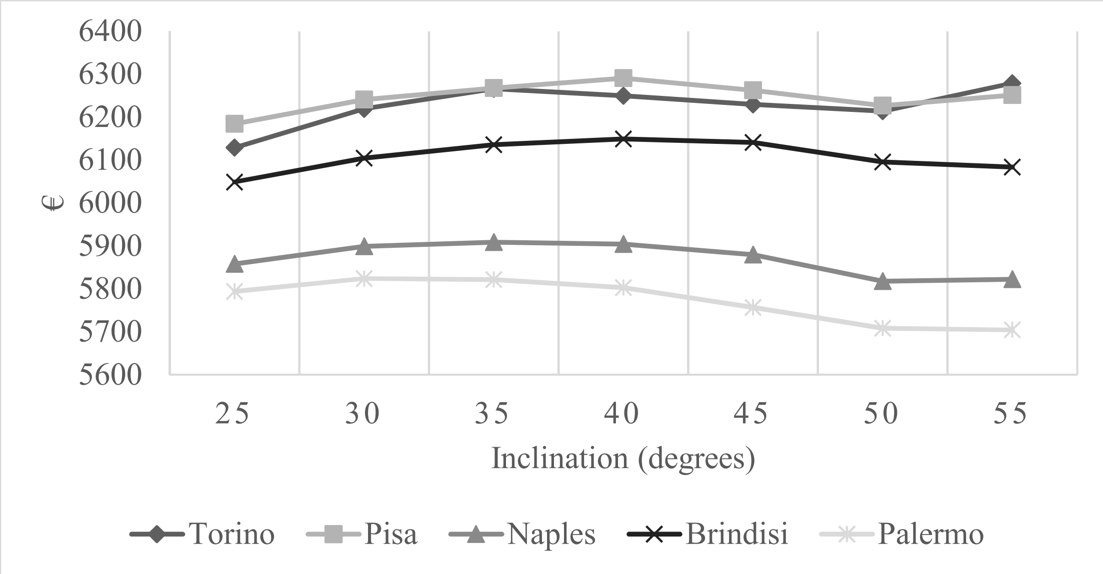

Figure 122: Net present value for different inclinations

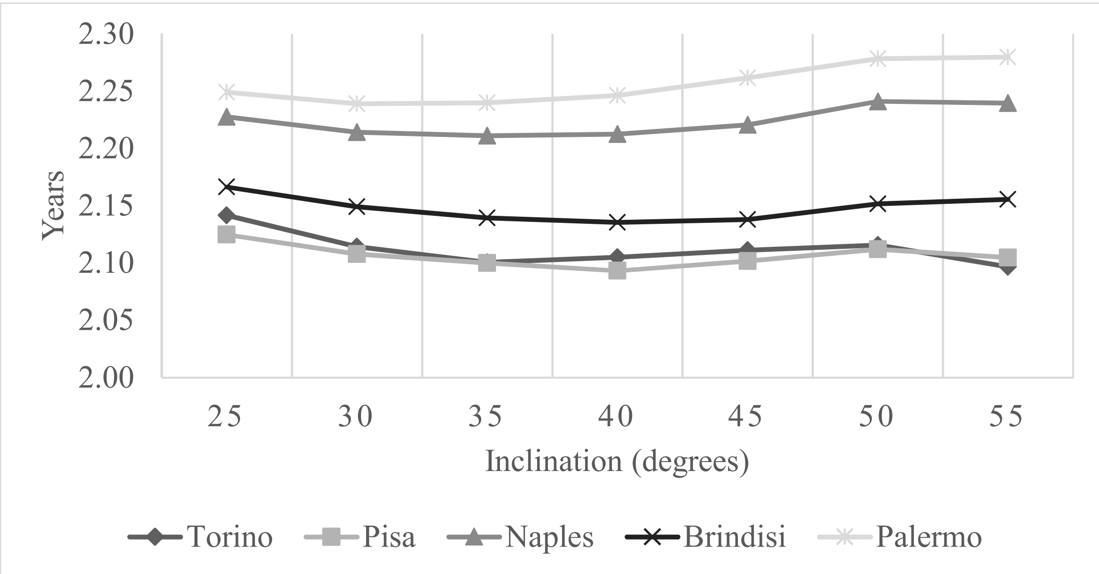

Figure 123: Payback period for different inclinations

In Figure 122, it is apparent that Pisa presents the highest net present value noticed in 40º with 6.291€ making the project more economically feasible and in Figure 123, the lowest payback period is in Pisa in the case of 40º with almost 2,1 years for the reason that where the economic benefit is higher the payback period will be shorter.

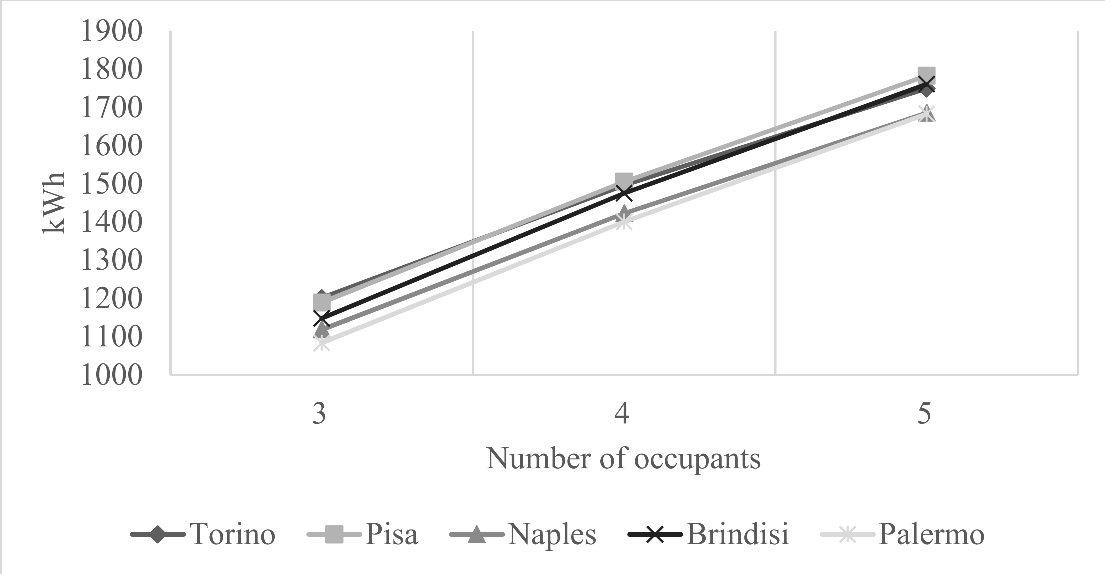

Figure 124: System energy for different occupants

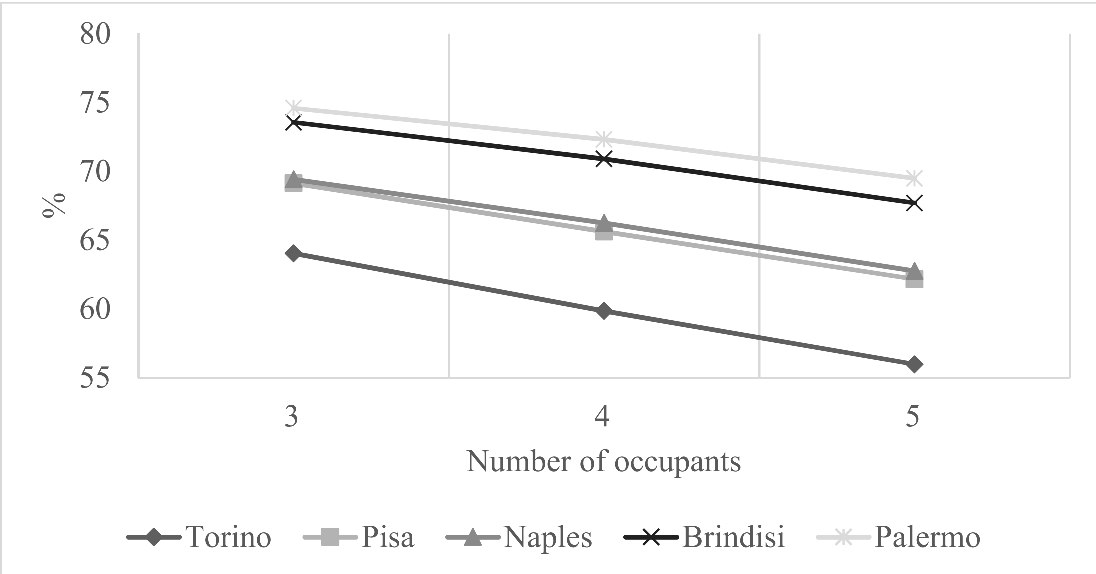

Figure 125: Solar fraction for different occupants

In Figure 124, it is evident that the most energy is produced in Pisa for 5 occupants reaching 1.782 kWh. Some solar gains that the domestic solar hot water system has during summer months may not be used and are lost. As the number of occupants increases, their energy demand also increases and these extra solar gains that were not previously used are in favor to cover the occupants' needs. In Figure 125, solar fraction presents a decrease as the number of occupants increases. Palermo has the highest solar fraction observed for 3 occupants being almost 75% and their average hot water usage equals to 150 kg/day. Despite the fact that the energy produced by the system is increasing, the energy demand is higher and as a result the solar fraction is diminishing.

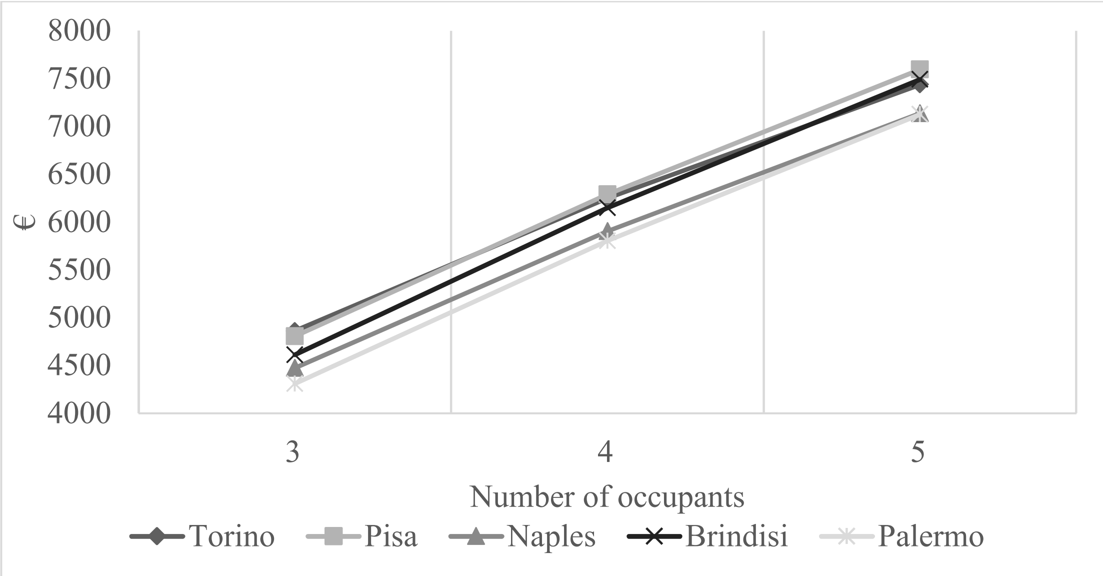

Figure 126: Net present value for different occupants

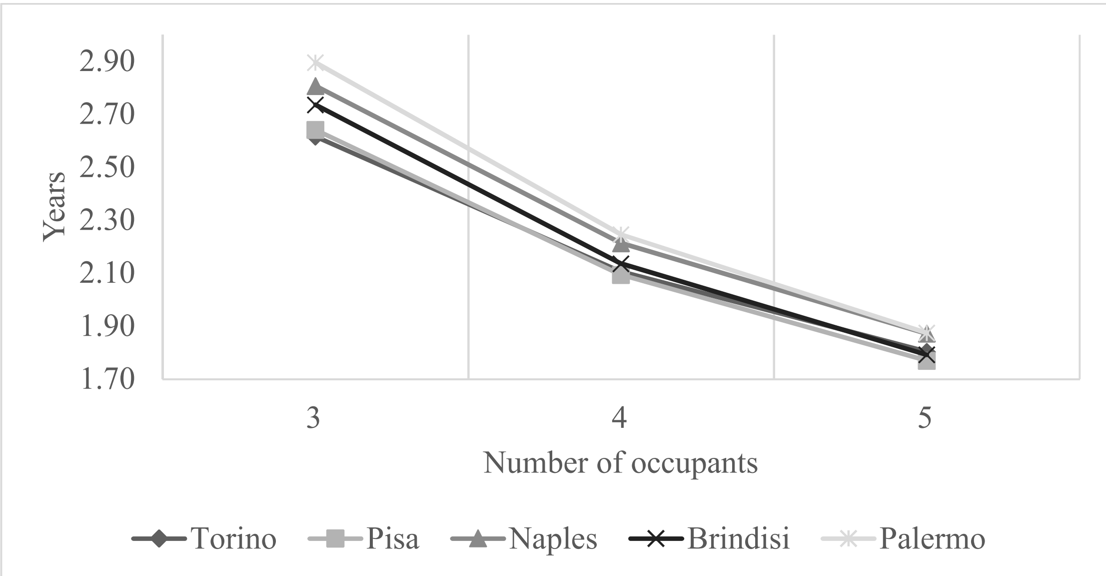

Figure 127: Payback period for different occupants

As shown in Figure 126, Pisa has the highest net present value observed at 7.594€ in for 5 occupants. This makes the project more economically feasible since the energy produced by the system in this case is the highest one. In Figure 127, the payback period is lowest in Pisa for 5 occupants for almost 1,8 years which is in accordance to where there are large economic benefits, the payback period will be shorter.

It can be concluded that among the five locations of Italy, the base case scenario (4 occupants, collector area= 4 m^2, $F_R(\tau\alpha)$= 0,76, F_RU_L= 4,5 W/m^2 C, inclination= 40°) presents better performance in Pisa in all aspects except for the solar fraction for which Palermo has the highest one mainly due to less energy demand. In the first parametric analysis, the system produces more energy in Torino in the case of 3 collectors and has also the highest net present value. Regarding solar fraction, Palermo in the case of 3 collectors has the highest one and in general as the number of collectors increases, the solar fraction also increases but not with the same rate mainly because of the different energy demand during summer and winter months. The payback period is shorter in Pisa and Brindisi in the case of 1 collector without large differences among the others. Furthermore, the next parametric analysis showed that for system energy Pisa presents the highest one in 0,22 m^3. Additionally, the parametric analysis having as input the inclination of the system showed that Pisa had the best results in 40° regarding system energy, net present value and payback period. Palermo presented the highest values for solar fraction in the case of 30° and 35°. Palermo is located at North Italy and has a hot summer Mediterranean climate with mild and wet winters and hot and dry summers. After 50° there is a small increase because of some potential solar earnings the system may have during winter months. Finally, in the parametric analysis for the number of occupants, Pisa presented the highest value for 5 occupants in system energy. As the number of occupants increases, the system takes advantage of the solar gains which in other cases (3 or 4 occupants) are lost and raises its energy production. Palermo had the highest solar fraction for 3 occupants. Even if the domestic solar hot water system produces more energy for 5 occupants, the total energy required for them remains higher. It is reasonable since the less the number of people and their average daily hot water usage of 150 kg/day, the domestic solar hot water system can provide more coverage for their needs. Pisa presents the highest net present value and the shortest payback period for 5 occupants following the essential of where the economic benefits are higher, the shorter is the payback period of the initial investment as electricity replacement.

Having calculated the solar fraction for various household types in five locations in Italy, a rough estimation of the total energy conservation that the use of solar thermal systems has in Italy is performed. According to the Italian National Institute of Statistics [67] the average size of a typical household consists of 3 occupants. The average solar fraction of the locations that corresponds to this number of occupants is 70,5% which means that the amount of energy saved annually from a domestic solar hot water system similar to the base case scenario results to 1.148 kWh per system. Taking into consideration the total glazed area of the country and the residential energy consumption [63], the total energy conservation for all systems in Italy during the last 11 years is estimated.

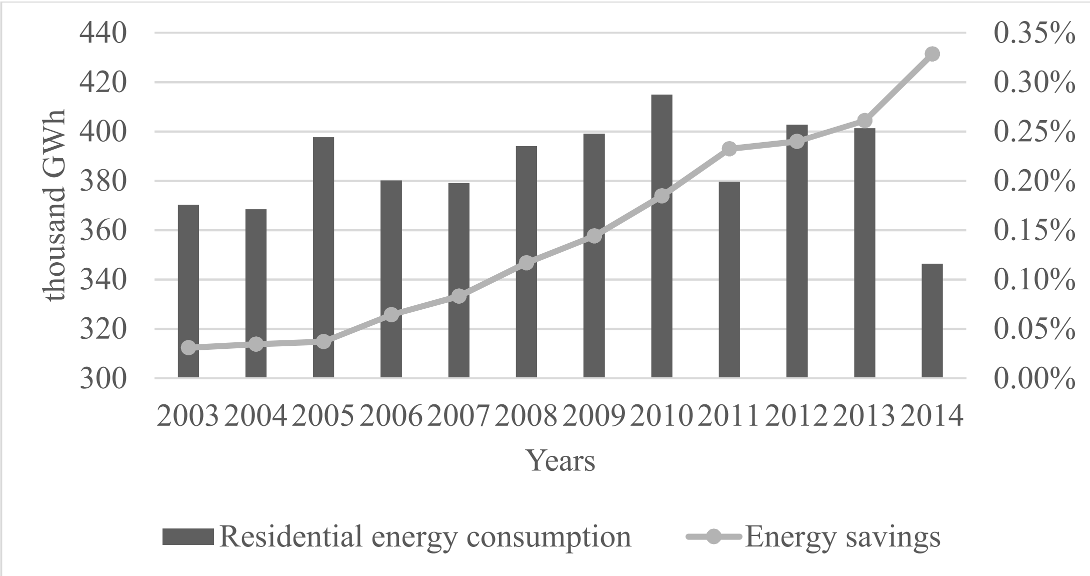

Figure 128: Total energy conservation

As presented in Figure 128, the total energy conservation increased during the last years as more systems were installed. It started with 114 GWh in 2003 and resulted to 1.137 GWh in 2014. Since 2005, energy consumption in the residential sector has started to decrease except for some increases. The reduction was influenced by economic performance, lower heat consumption due to better climatic conditions, more efficient electrical appliances and heating systems. In 2003, the potential energy savings deriving from the domestic solar hot water systems accounted for 0,03% of the total residential energy consumption. These savings reached to 0,33% of the total residential energy consumption in Italy in 2014.

In order to estimate the emissions reduction of GHG because of the domestic solar hot water systems usage, the emission factors for Italy per kWh of electricity generated were taken into consideration [64].

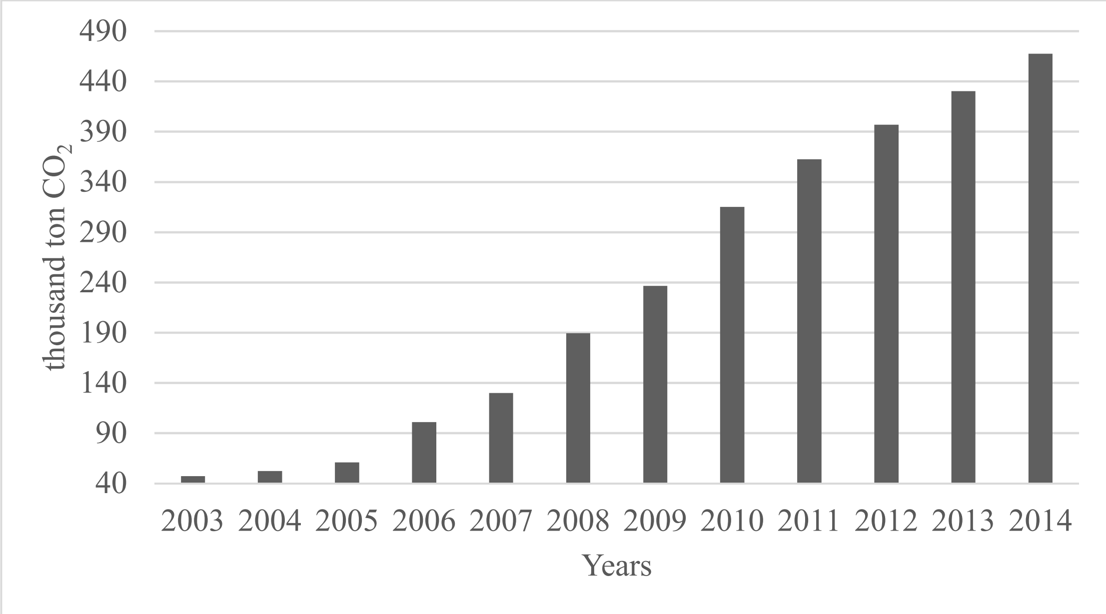

Figure 129: Tons of CO_2 saved

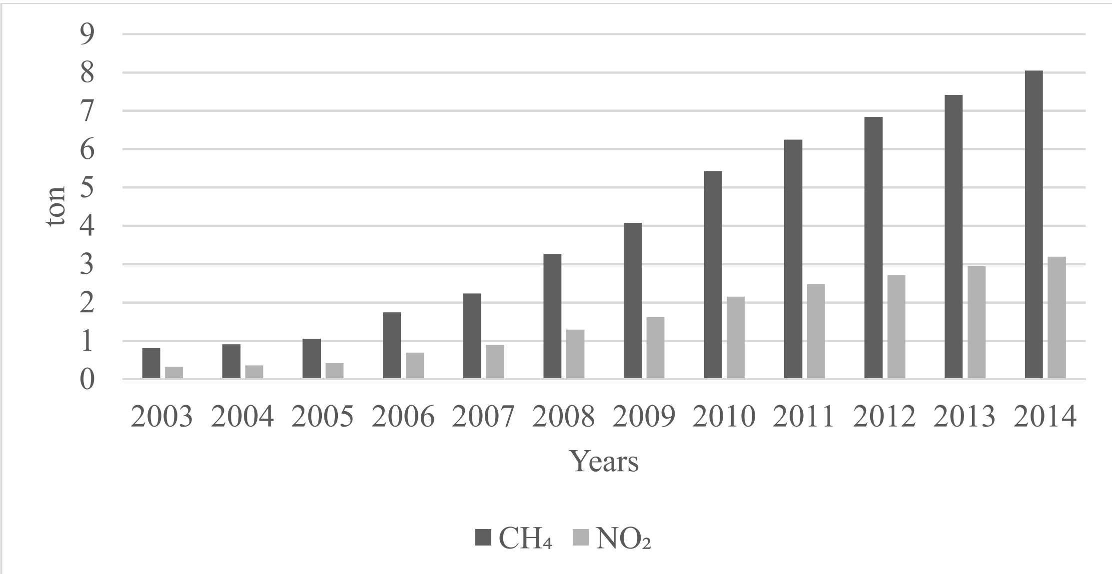

Figure 130: Tons of CH_4 and NO_2 saved

As presented in Figure 129, there was a steady increase for thousand tons of CO_2 saved by the domestic solar hot water systems usage from 2003 to 2014. It started with 47 thousand tons in 2003 and reached 467 thousand tons in 2014. The same happened with CH_4 and NO_2, as presented in Figure 130, that started with 0,8 and 0,3 tons in 2003 and reached 8 and 3,2 tons in 2014 respectively.

4.5. SPAIN

The locations examined for Spain are the metropolitan areas of Santander in Northern Spain, the capital Madrid in Central Spain, Palma in Western Spain and Sevilla in Southern Spain in order to cover all the different climatic conditions and for which full meteorological data in TMY format were available.

Table 7: Coordinates and elevation of locations

Location	Latitude	Longitude	Elevation
Santander	43,47°	-3,82°	40 m
Madrid	40,45°	-3,55°	582 m
Palma	39,55°	2,73°	8 m
Sevilla	37,42°	-5,9°	31 m

The latitude, longitude and elevation of each location are presented in Table 7. The total electricity rate for Spain, incorporating all taxes and energy prices, is 0,237 €/kWh [60]. The inclination is set at 40° and the inflation rate is set at 1%/year [40, 72]. The average daily hot water usage is 50 kg/day/person and the solar tank has a volume of 0,2 m^3.

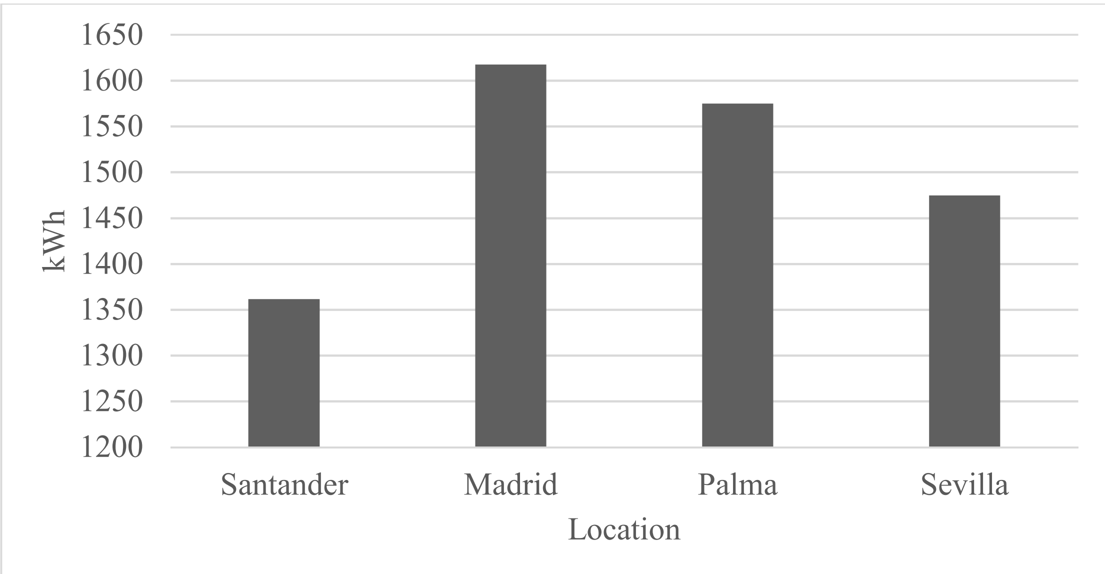

Figure 131: System energy

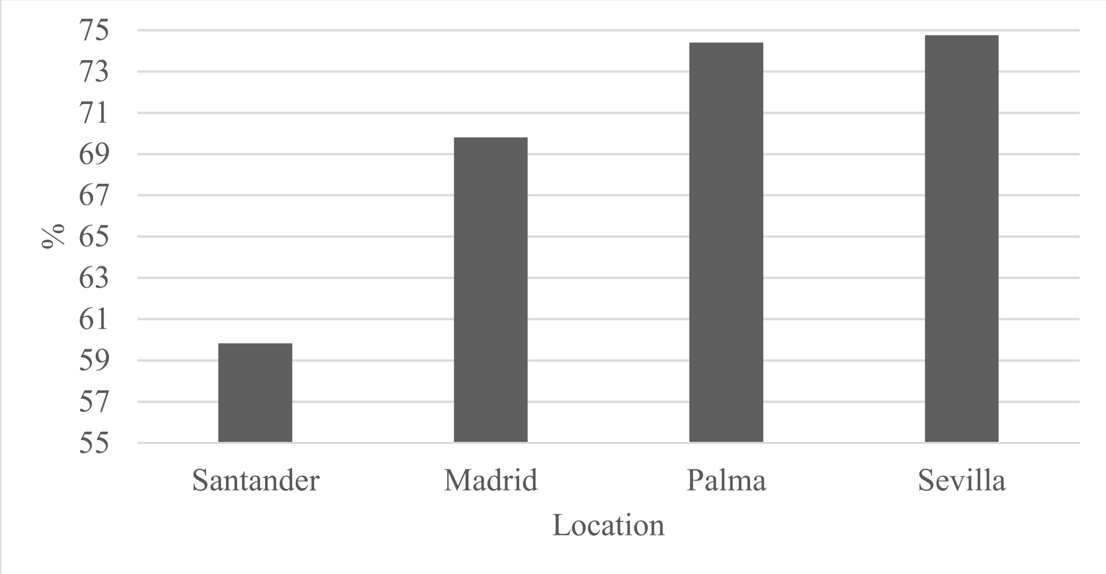

Figure 132: Solar fraction of the system

In Figure 131, it is evident that the highest amount of energy is produced in Madrid with almost 1.618 kWh and the lowest in Santander with 1.362 kWh. In Figure 132, it is shown that the solar fraction ranges from 60% to 75% with Sevilla presenting the highest one. This shows that the energy produced by the domestic solar hot water system in Sevilla is enough to cover 75% of the total energy demand compared to the other locations' demand. Sevilla's energy demand of 1.973 kWh is lower than Santander's 2.276 kWh, Madrid's 2.317 kWh and Palma's 2.117 kWh along with the fact that the system in Sevilla has larger solar gains during winter months.

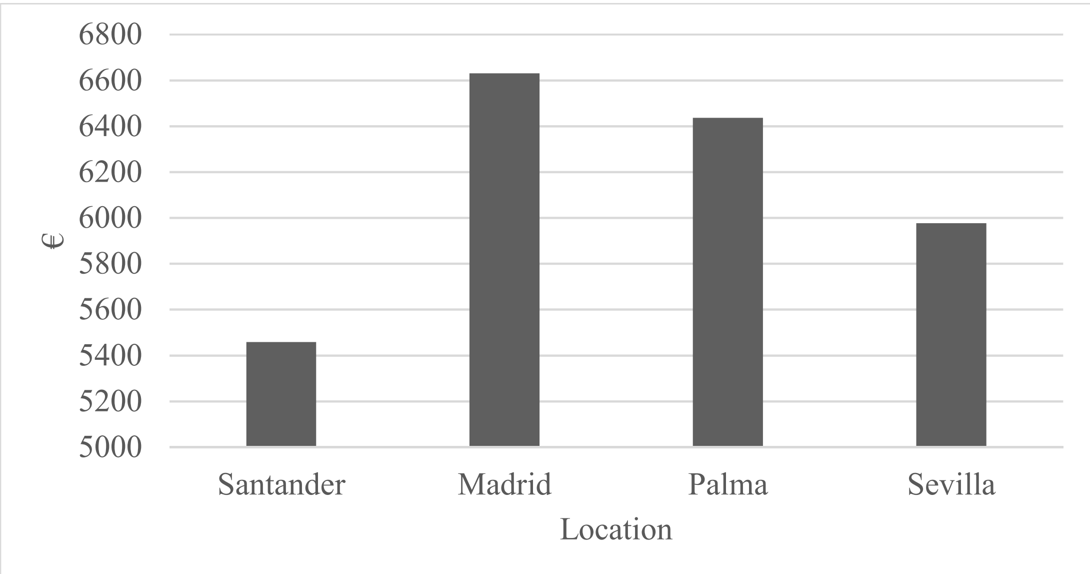

Figure 133 Net present value of the system

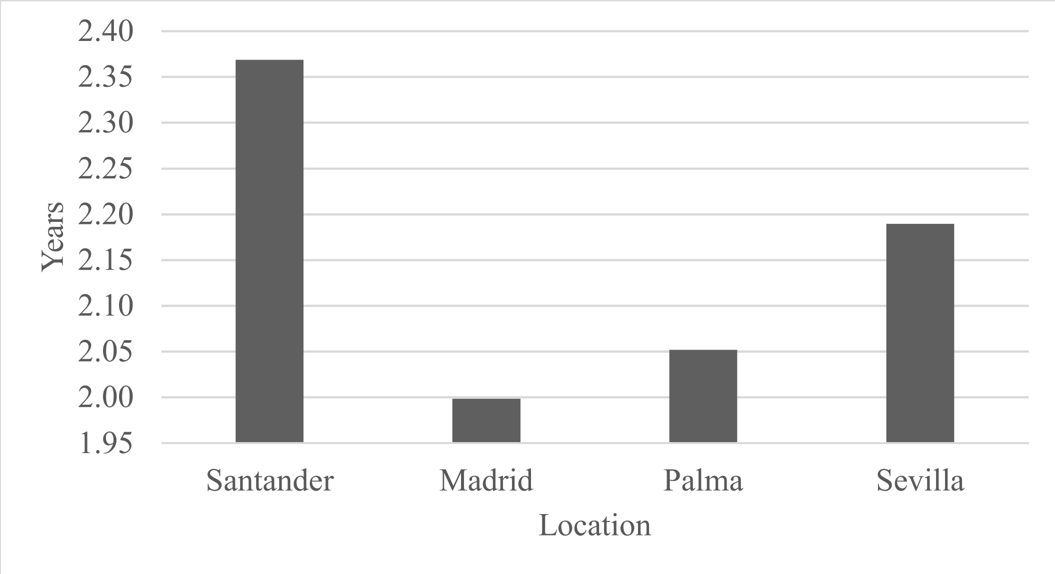

Figure 134: Payback period of the system

As presented in Figure 133, the highest net present value of the system is observed in Madrid with almost 6.631€. That makes the project more economical feasible in this location due to higher energy production. In Figure 134, Madrid has the lowest payback period of 2 years which is in accordance to where the economic benefits are higher, the payback period will be shorter.

Having concluded with the base case scenario for each location a number of parametric simulations is made in order to examine the influence of different inputs to system energy, solar fraction, net present value and payback period of the domestic solar hot water system. The first parametric analysis has as input the number of collectors taking into consideration 1, 2 and 3 collectors. In addition, the next parametric analysis has as input the solar tank volumes including 0,18 m^3, 0,2 m^3 and 0,22 m^3 while the other parametric has as input the inclinations for the solar collectors ranging from 25º to 55º in steps of 5º. Finally, the last parametric has as input the number of occupants considering 3, 4 and 5 occupants regarding their average daily hot water usage of 150 kg/day, 200 kg/day and 250 kg/day respectively.

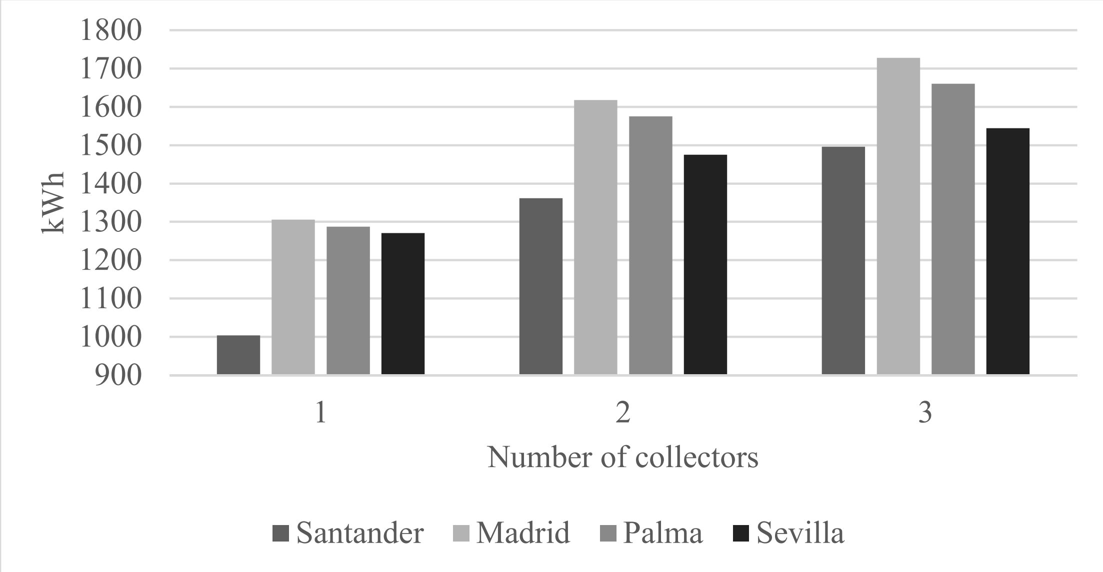

Figure 135: System energy for different collectors

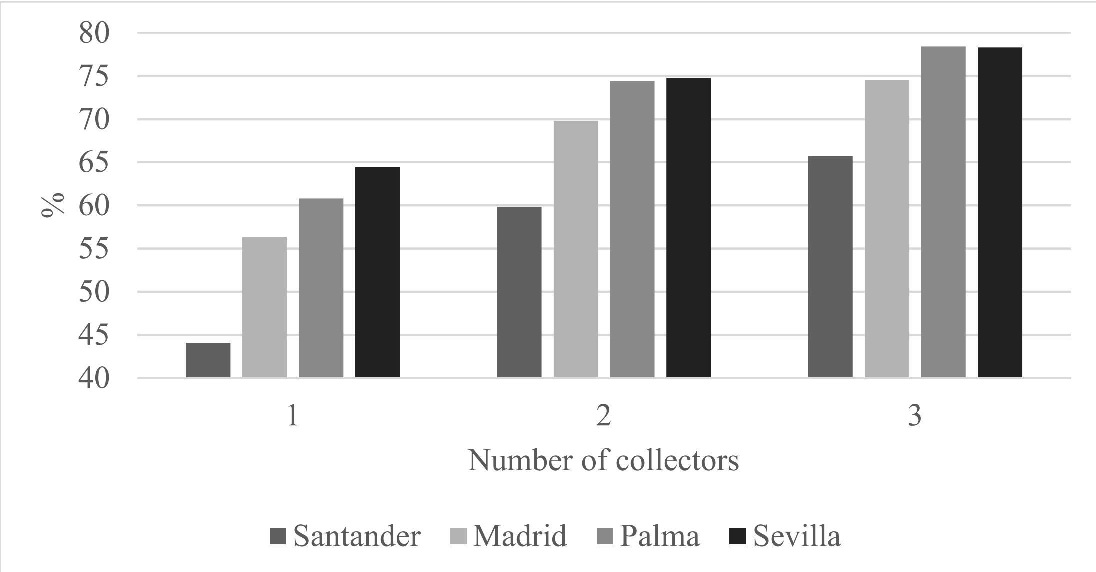

Figure 136: Solar fraction for different collectors

As presented in Figure 135, the system produces more energy as the number of collectors increases and Madrid presents the highest values by 1.305 kWh, 1.618 kWh and 1.727 kWh. As shown in Figure 136, Sevilla presents the highest solar fraction in all cases. As the number of collectors increases, the solar fraction also does but not proportionately. Going from 1 collector to 2 collectors there is an increase of almost 10% but from 2 to 3 collectors the increase is 4%. During the summer months the energy demand is lower than the winter months. By having more than 2 collectors solar fraction will have a small increase since the energy produced by the system may increase but the demand is less than the winter months.

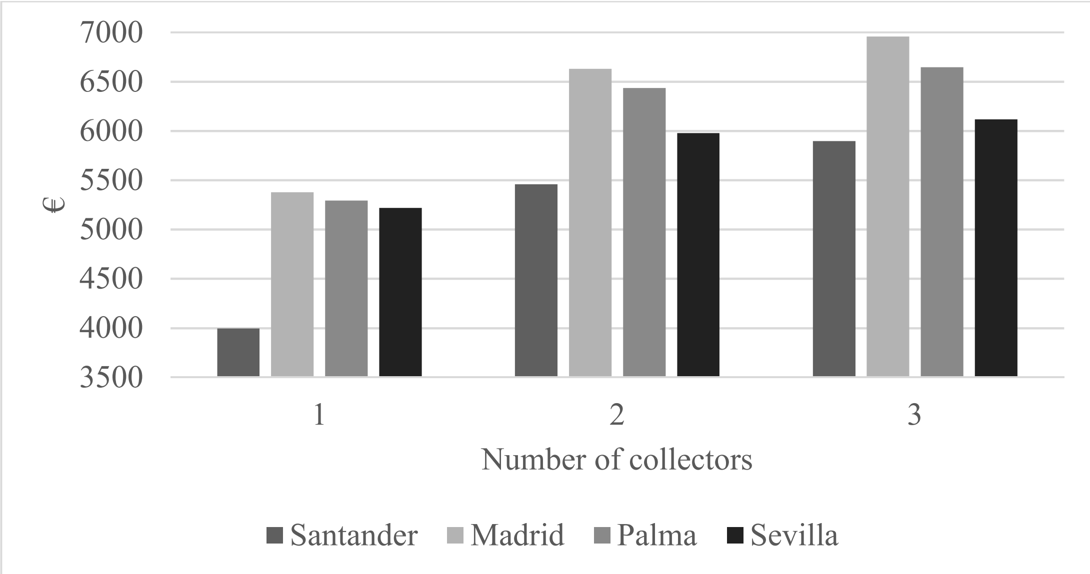

Figure 137: Net present value for different collectors

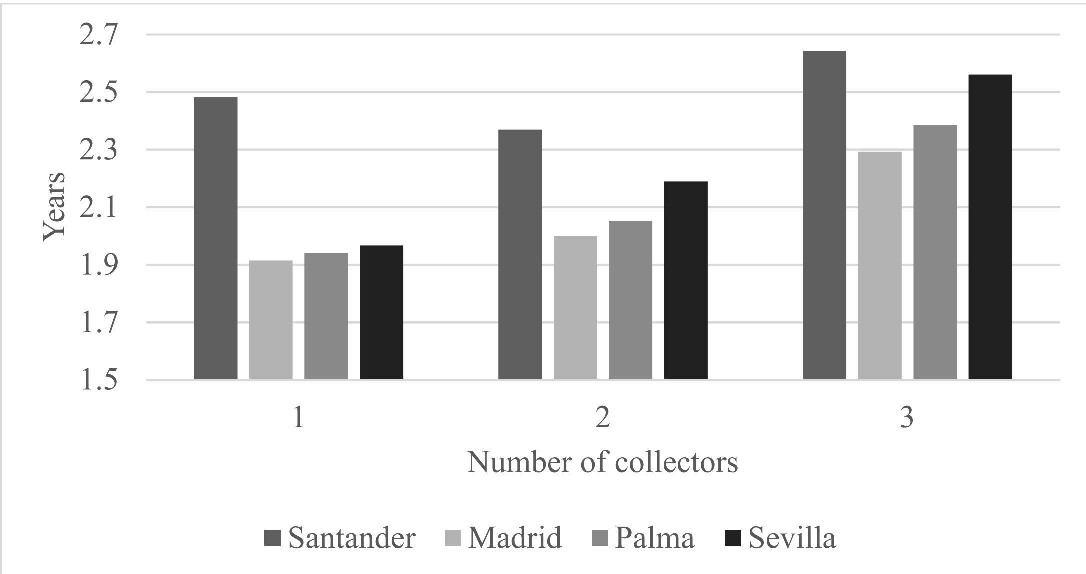

Figure 138: Payback period for different collectors

In Figure 137, the highest net present value is noticed in Madrid with 5.378€, 6.631€ and almost 6.957€ that makes the project more economical feasible in the case of 3 collectors where more energy is produced. From Figure 138, it is evident that Madrid presents the lowest payback period in all cases which follows the logic of where the economic benefit is higher, the payback period will be shorter.

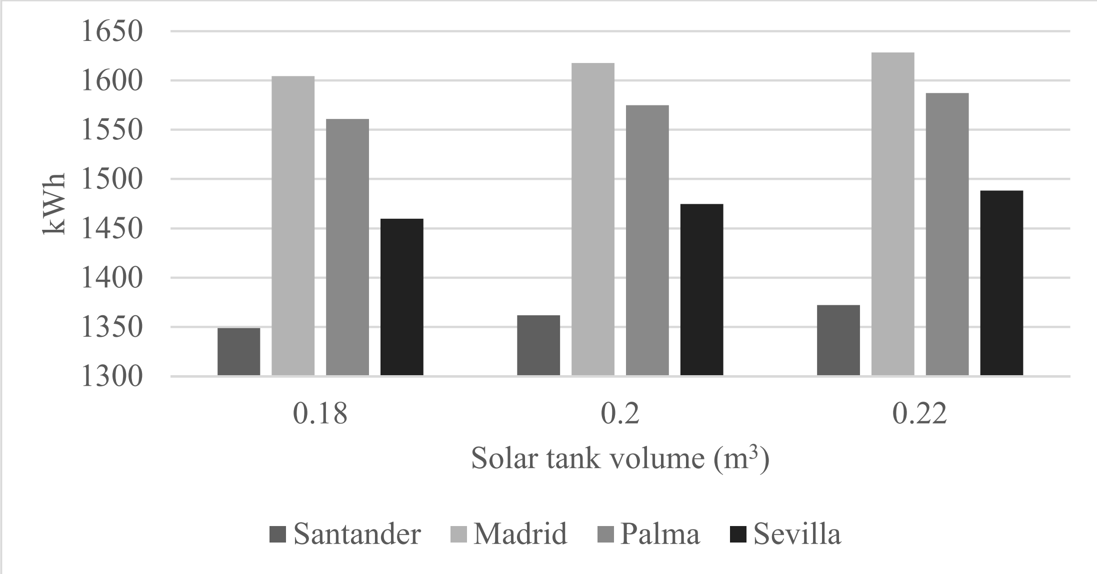

Figure 139: System energy for different solar tank volumes

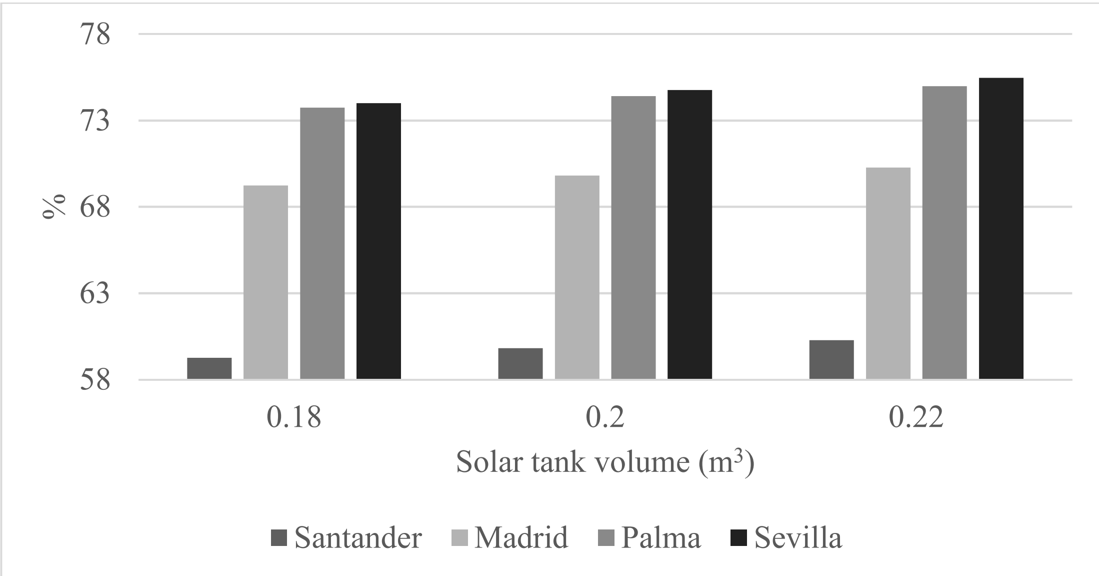

Figure 140: Solar fraction for different solar tank volumes

As shown in Figure 139, the total energy produced by the domestic solar hot water system does not present large differences while the solar tank volume increases since the only thing that changes is the volume where water is stored. Madrid presents the highest values. As presented in Figure 140, Sevilla has the highest solar fractions also without large differences and the increase in the solar tank volumes does not influence coverage as much because the difference among them is 0,02 m^3 and the energy input of the domestic solar hot water system has small changes.

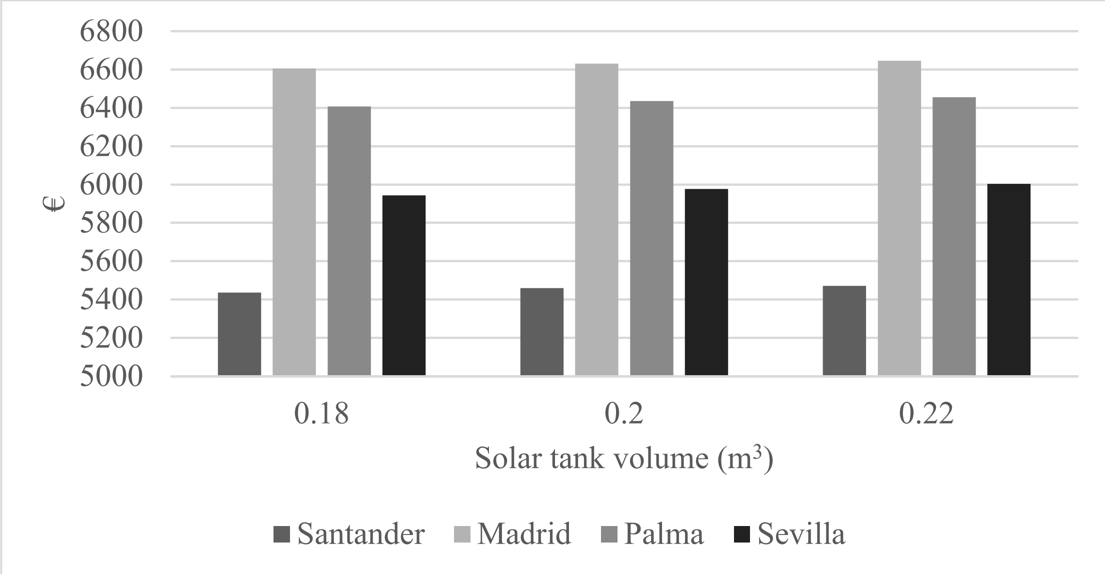

Figure 141: Net present value for different solar tank volumes

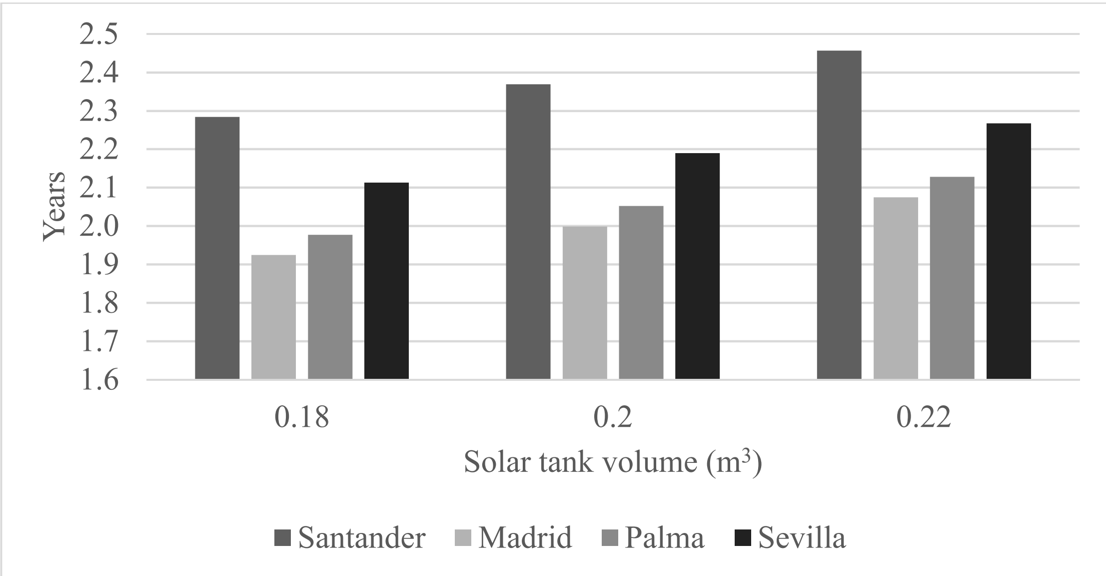

Figure 142: Payback period for different solar tank volumes

In Figure 141, it is shown that Madrid presents the highest net present value with small changes making the project more economically feasible in this location and for this reason in Figure 142, Madrid has the lowest payback period.

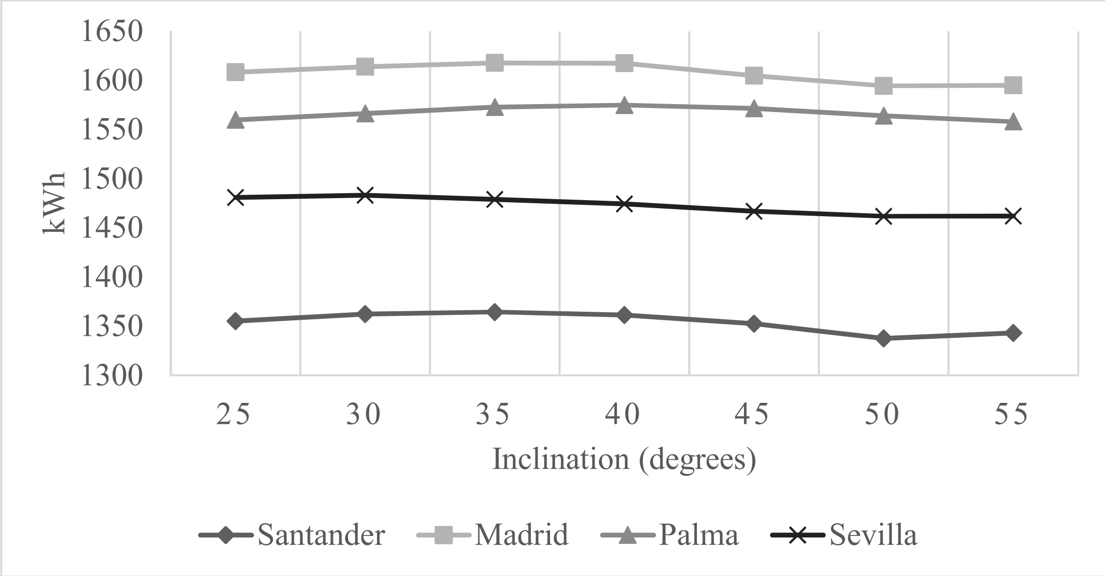

Figure 143: System energy for different inclinations

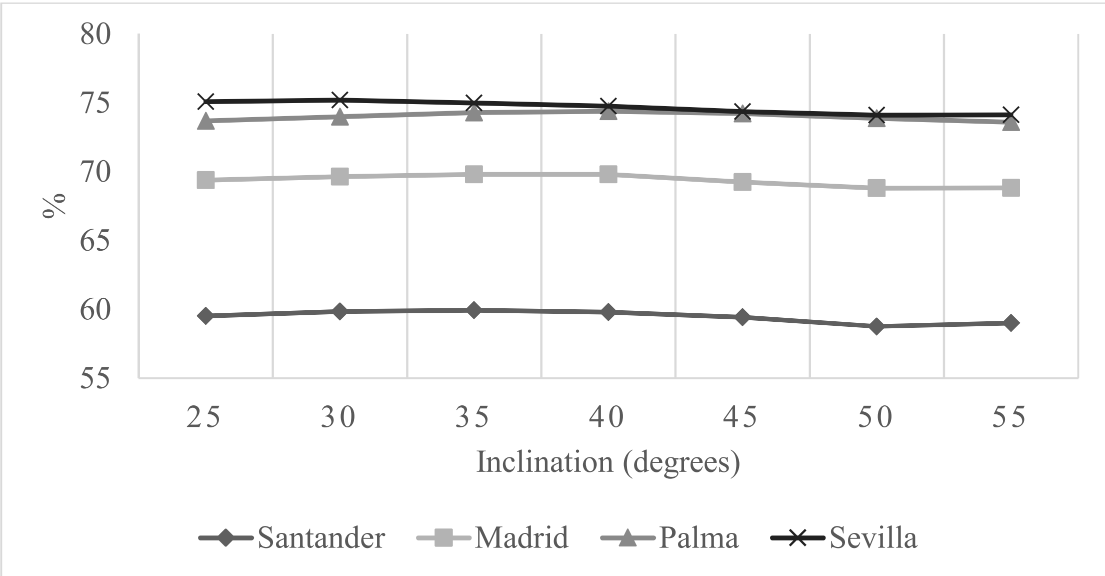

Figure 144: Solar fraction for different inclinations

In Figure 143, it is apparent that the most energy is produced in Madrid in the case of 35º with 1.618 kWh while in Figure 144 the solar fraction is higher in Sevilla with the highest observed in 30º with 70,2%. The domestic solar hot water system produces more energy in Madrid but the solar fraction is highest in Sevilla due to the fact that the energy demand is lower than it is in Madrid. In all cases it is observed that after 30º and 35º the solar fraction and the system energy is decreasing. The small increase between 50º and 55º is due to the fact that the locations may take advantage of solar radiation during winter months.

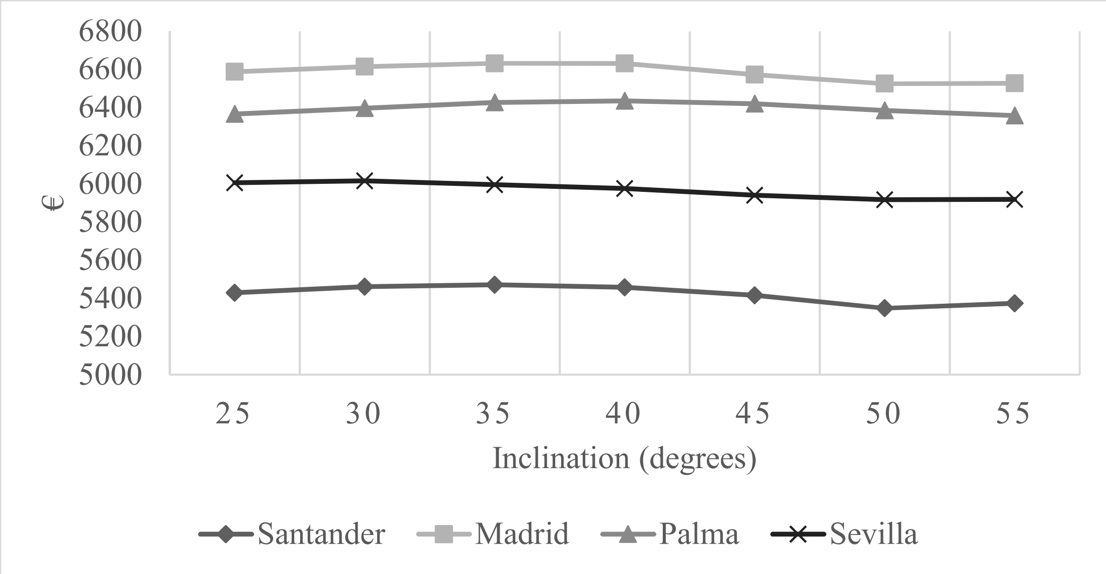

Figure 145: Net present value for different inclinations

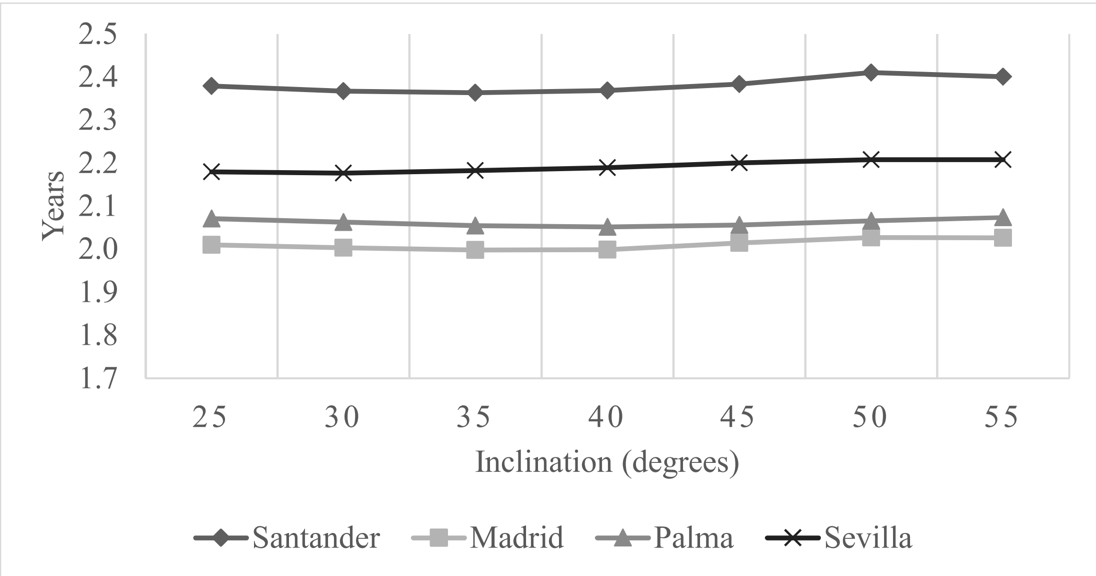

Figure 146: Payback period for different inclinations

In Figure 145, it is apparent that Madrid presents the highest net present value without large differences making the project more economically feasible in this location and in Figure 146, the lowest payback period is also presented in Madrid with 2 years because of where the economic benefits are higher the payback period will be shorter.

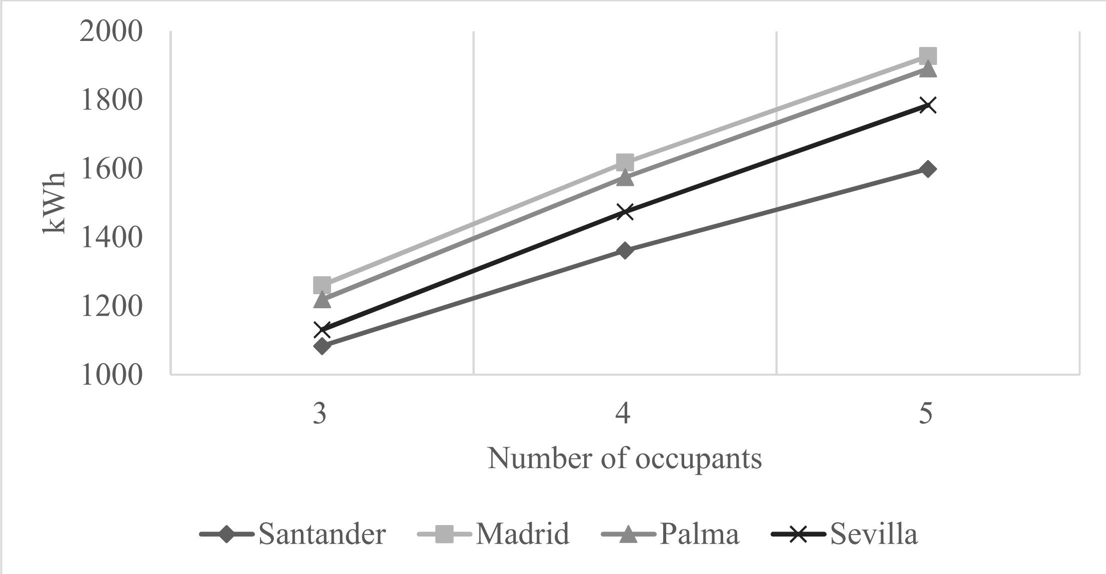

Figure 147: System energy for different occupants

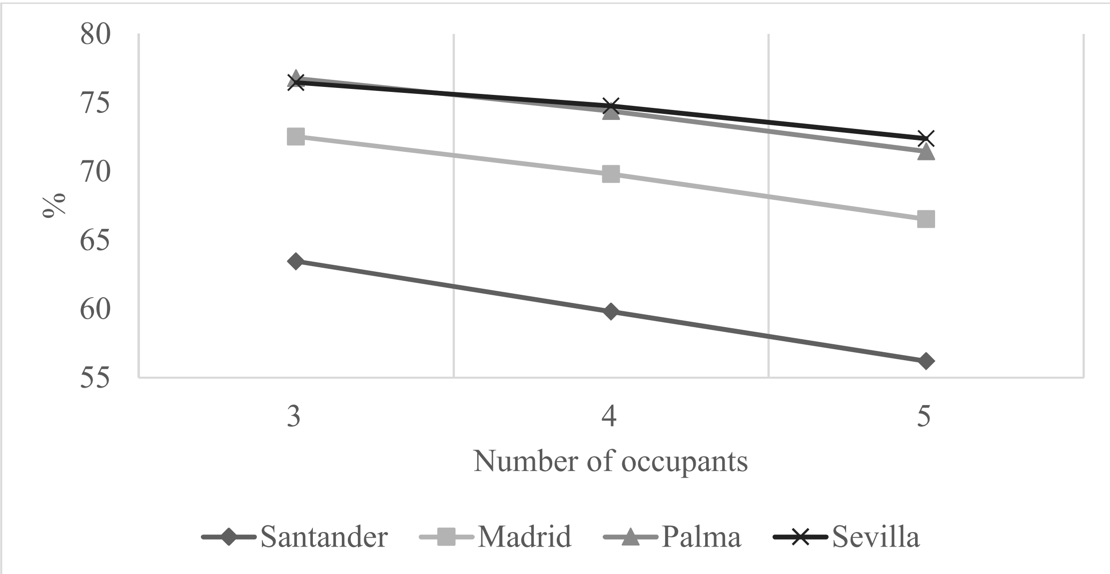

Figure 148: Solar fraction for different occupants

In Figure 147, it is apparent that the most energy is produced in Madrid for 5 occupants reaching 1.927 kWh. Some solar gains that the domestic solar hot water system has during summer months may not be used and are lost. As the number of occupants increases, their energy demand also increases and these extra solar gains that were not previously used are in favor to cover the occupants' needs. In Figure 148, solar fraction presents a decrease as the number of occupants increases. Sevilla and Palma have the highest solar fraction observed for 3 occupants being 76,5% and 76,8% and their average daily hot water usage equals to 150 kg/day. Despite the fact that the energy produced by the system is increasing, the total energy required is higher and as a result the solar fraction is diminishing.

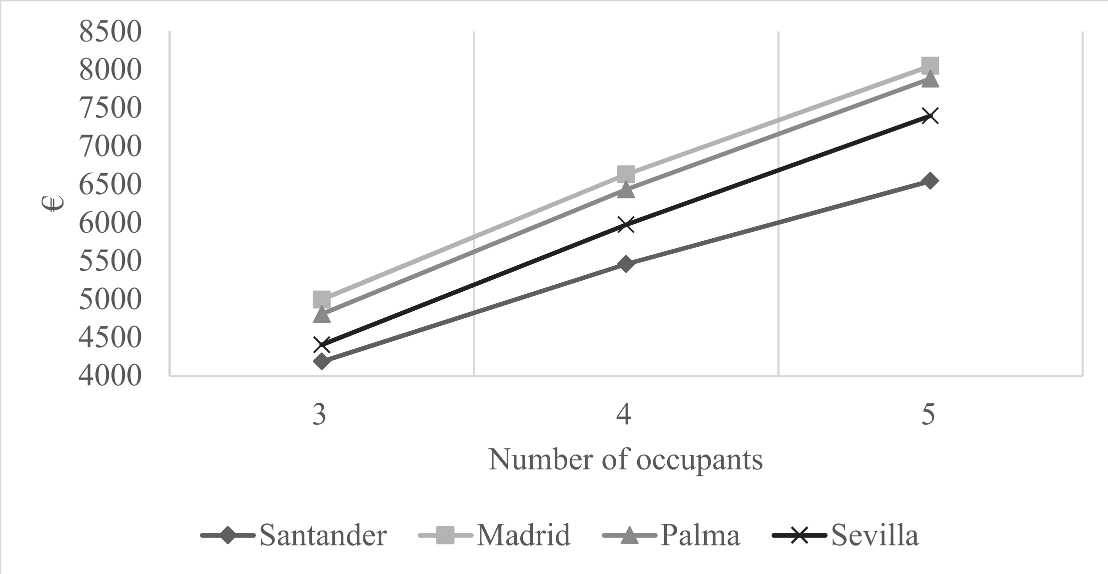

Figure 149: Net present value for different occupants

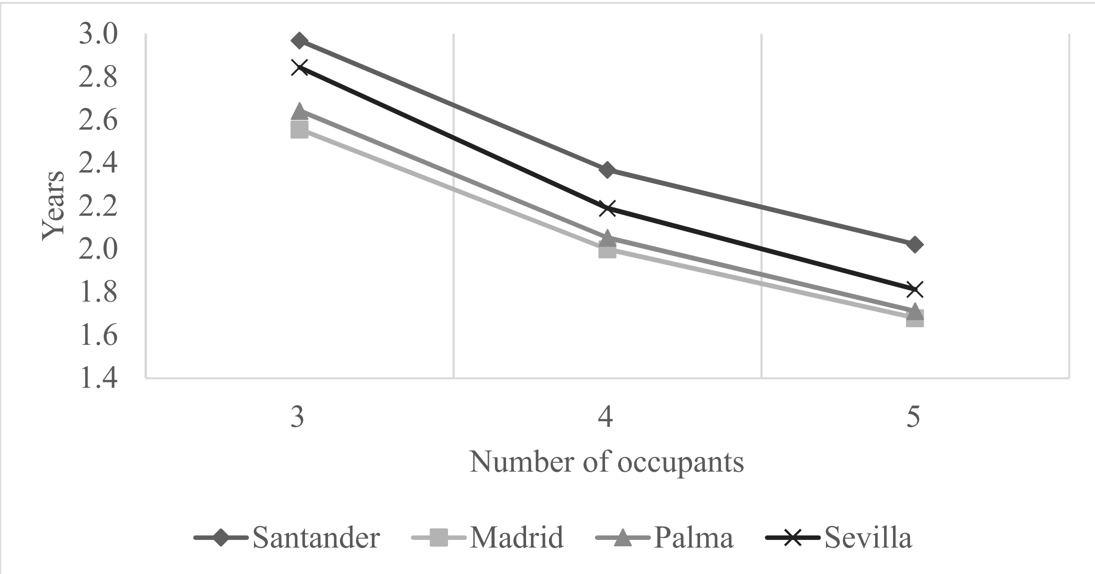

Figure 150: Payback period for different occupants

As shown in Figure 149, Madrid has the highest net present value observed at 7.882€ for 5 occupants. That makes the project more economically feasible because of the more energy production. In Figure 150, the payback period is lowest in Madrid for 5 occupants for 1,7 years which is in accordance to where there are large economic benefits, the payback period will be shorter.

It can be concluded that among the four locations of Spain, the base case scenario (4 occupants, collector area= 4 m^2, $F_R(\tau\alpha)$= 0,76, F_RU_L= 4,5 W/m^2 C, inclination= 40º) presents better performance in Madrid except for solar fraction that Sevilla presents higher values mainly due to less energy demand. In the first parametric analysis, the system produces more energy in Madrid in the case of 3 collectors and has also the highest net present value along with the shortest payback period. In the first parametric analysis, the system produces more energy in Madrid in the case of 3 collectors and has also the highest net present value along with the shortest payback period. Regarding solar fraction, Sevilla has the highest ones and in general as the number of collectors increases, the solar fraction also increases but not with the same rate mainly because of the different energy demand during summer and winter months. Furthermore, the next parametric analysis showed that for system energy Madrid presented the highest one in 0,22 m^3. Additionally, the parametric analysis having as input the inclination of the system showed that Madrid had the best results in 35º regarding system energy, net present value and payback period. Sevilla presented the highest values for solar fraction in the case of 30º. Seville is located in Northern pain and has a subtropical Mediterranean climate with dry summers and wet winters. After 50º there is a small increase because of some potential solar earnings the system may have during winter months. Finally, in the parametric analysis for the number of occupants, Madrid presents the highest value for 5 occupants in system energy. As the number of occupants increases, the system takes advantage of the solar gains which in other cases (3 or 4 occupants) are lost and raises its energy production. Sevilla has the highest solar fraction for 3 occupants. Even if the domestic solar hot water system produces more energy for 5 occupants, the total energy required for them remains higher. It is reasonable since the less the number of people and their average daily hot water usage of 150 kg/day, the domestic solar hot water system can provide more coverage for their needs. Sevilla presents the highest net present value and the shortest payback period for 5 occupants following the essential of where the economic benefits are higher, the shorter is the payback period of the initial investment as electricity replacement.

Having calculated the solar fraction for various household types in four locations in Spain, a rough estimation of the total energy conservation that the use of solar thermal systems has in Spain is performed. According to the Instituto Nacional de Estadistica

[68] the average size of a typical household consists of 3 occupants. The average solar fraction of the locations that corresponds to this number of occupants is 72,3% which means that the amount of energy saved annually from a domestic solar hot water system similar to the base case scenario results to 1.174 kWh per system. Taking into consideration the total glazed area of the country and the residential energy consumption [63], the total energy conservation for all systems in Germany during the last 11 years is estimated.

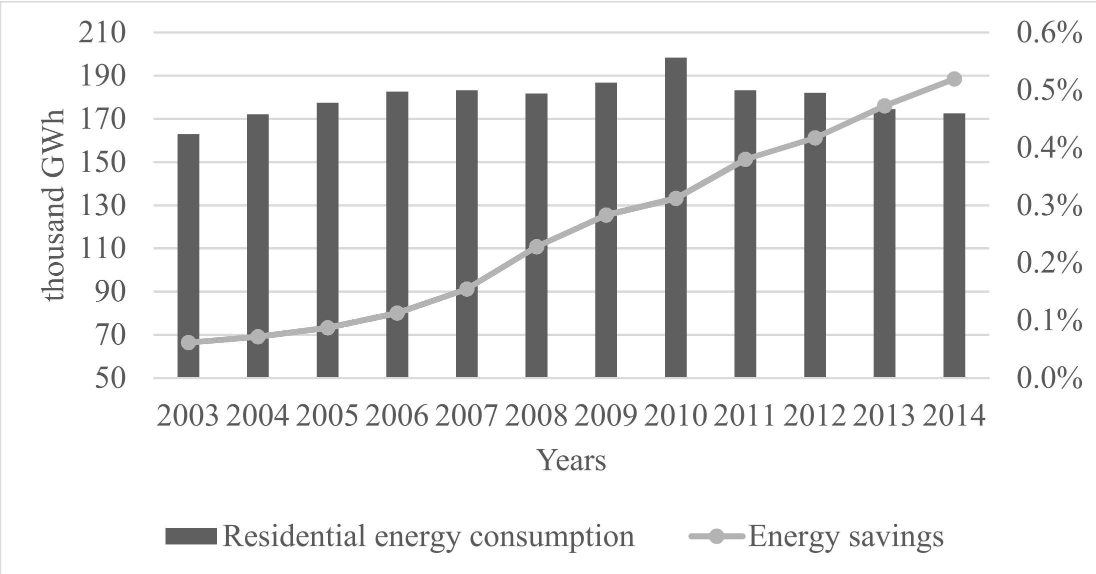

Figure 151: Total energy conservation

As presented in Figure 151, the total energy conservation increased during the last years as more systems were installed. It started with 100 GWh in 2003 and resulted to 896 GWh in 2014. Since 2010, energy consumption in the residential sector has started to decrease. The reduction was influenced by economic performance, lower heat consumption due to better climatic conditions, more efficient electrical appliances and heating systems. In 2003, the potential energy savings deriving from the domestic solar hot water systems accounted for 0,06% of the total residential energy consumption and reached to almost 0,5% of the total residential energy consumption in Spain in 2014.

In order to estimate the emissions reduction of GHG because of the domestic solar hot water systems usage, the emission factors for Spain per kWh of electricity generated were taken into consideration [64].

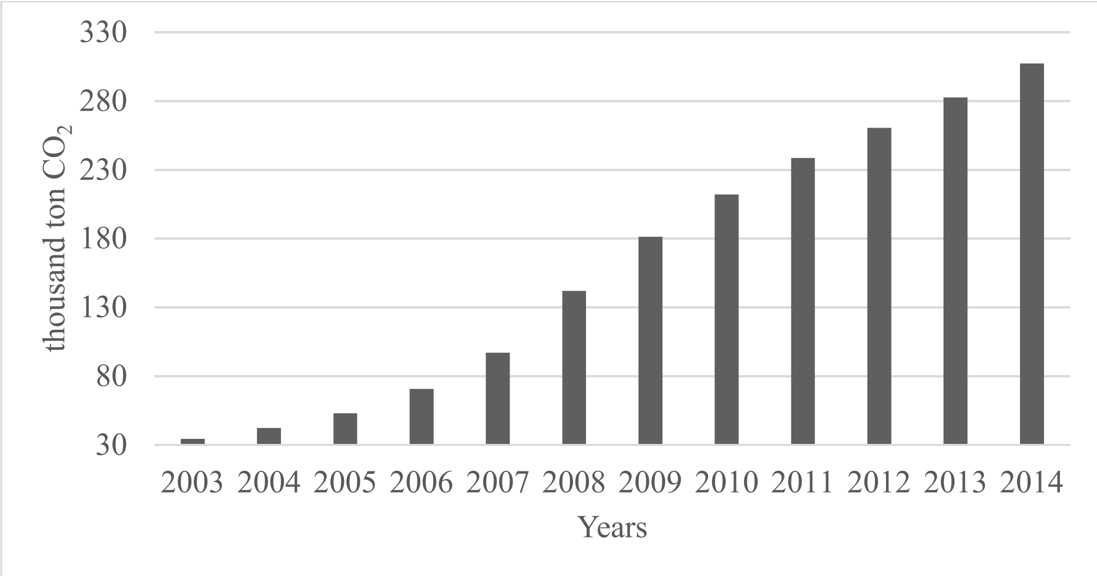

Figure 152: Tons of CO_2 saved

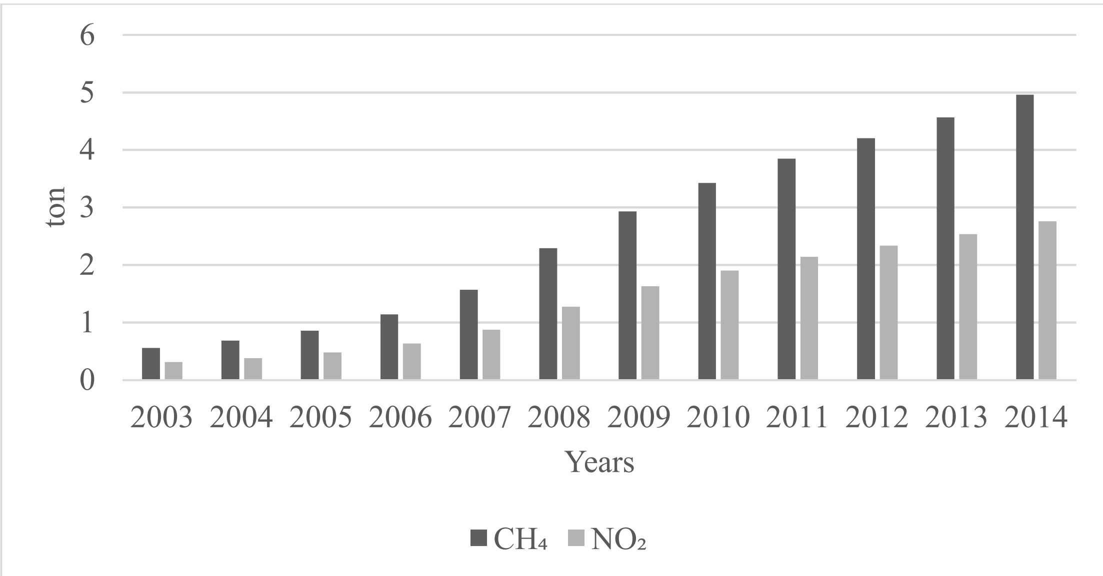

Figure 153: Tons of CH_4 and NO_2 saved

As presented in Figure 152, there was a steady increase of thousand tons of CO_2 saved by the domestic solar hot water systems usage from 2003 to 2014. It started with 34 thousand tons in 2003 and reached 307 thousand tons in 2014. The same happened with CH_4 and NO_2, as presented in Figure 153, that started with 0,6 and 0,3 tons in 2003 and reached almost 5 and 2,8 tons in 2014 respectively.

4.6. FRANCE

The locations examined for France are the capital Paris in Northern France, the metropolitan areas of Strasbourg in Eastern France, Nantes in Western France, Bordeaux in South West France and Nice in South East France in order to cover all the different climatic conditions and for which full meteorological data in TMY format were available.

Table 8: Coordinates and elevation of locations

Location	Latitude	Longitude	Elevation
Paris	48.73°	2,4°	96 m
Strasbourg	48,55°	7,63°	154 m
Nantes	47.17°	-1.6°	27 m
Bordeaux	44,83°	-0,7°	61 m
Nice	43,65°	7,2°	10 m

The latitude, longitude and elevation of each location are presented in Table 8. The electricity rate for Italy, incorporating all taxes and energy prices, is 0,168 €/kWh [60]. The inclination is set at 45° and the inflation rate is set at 1%/year [40, 72]. The average daily hot water usage is 50 kg/day/person and the solar tank has a volume of 0,2 m^3.

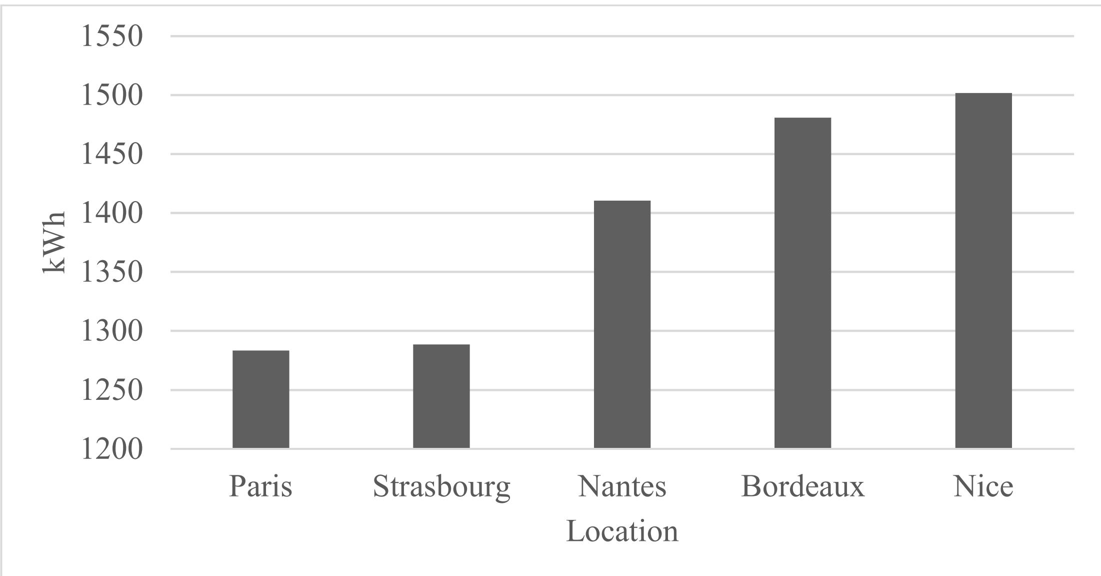

Figure 154: System energy

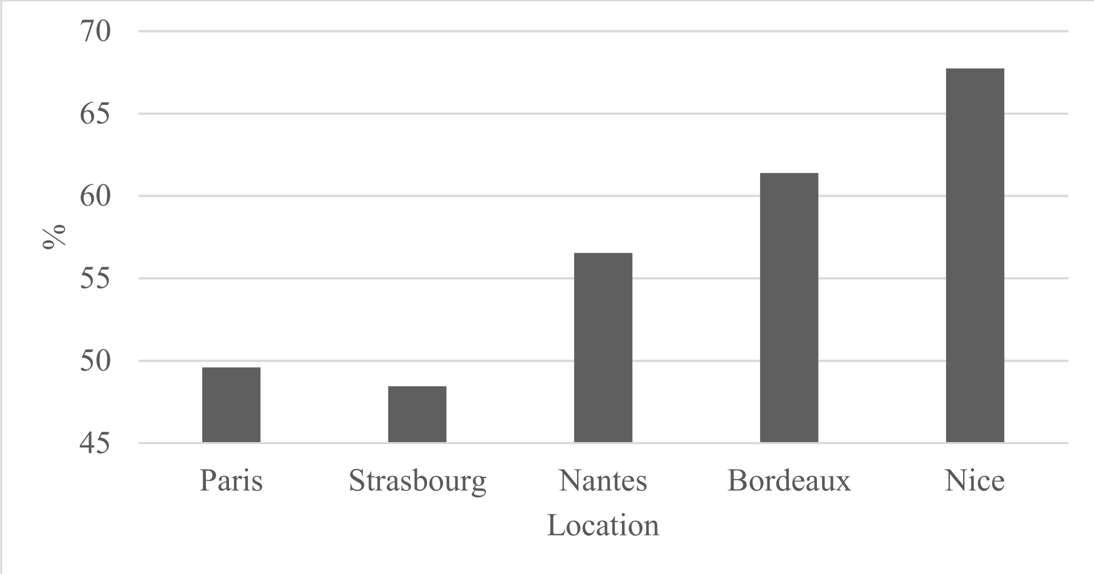

Figure 155: Solar fraction of the system

In Figure 154, it is evident that the highest amount of energy is produced in Nice with 1.500 kWh. In Figure 155, it is shown that the solar fraction ranges from 48,5% to 67,8% with Nice presenting the highest one. This shows that the energy produced by the domestic solar hot water system in Nice is enough to cover 67,8% of the energy demand compared to the other locations' demand. Nice has an energy demand of 2.217 kWh which is lower compared to Paris's 2.588 kWh, Strasbourg's 2.660 kWh, Nantes's 2.495 kWh and Bordeaux's 2.412 kWh along with the fact that the domestic solar hot water system in Nice is producing more energy during the winter months.

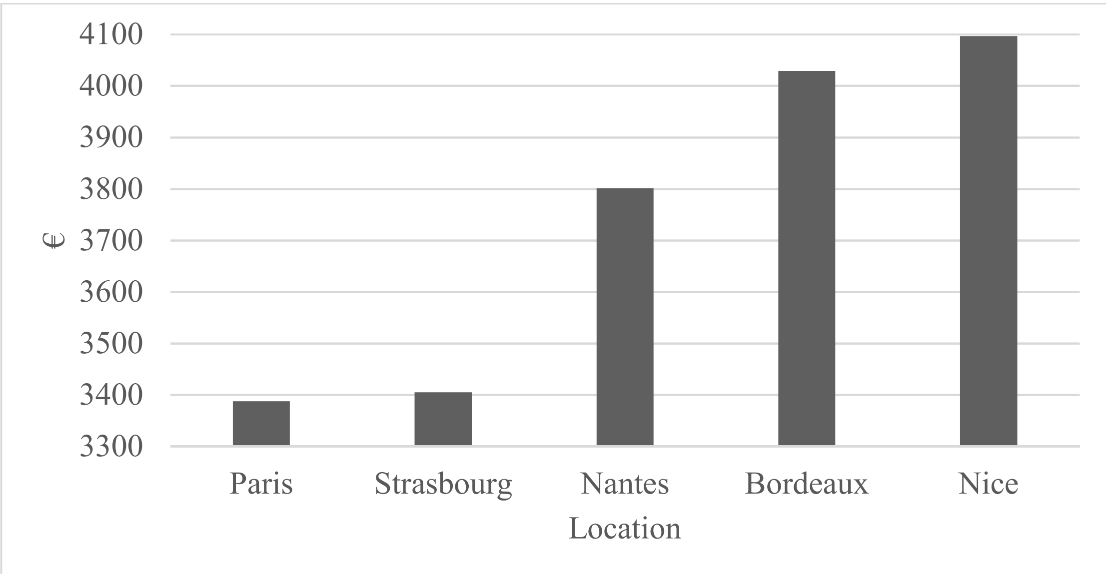

Figure 156: Net present value of the system

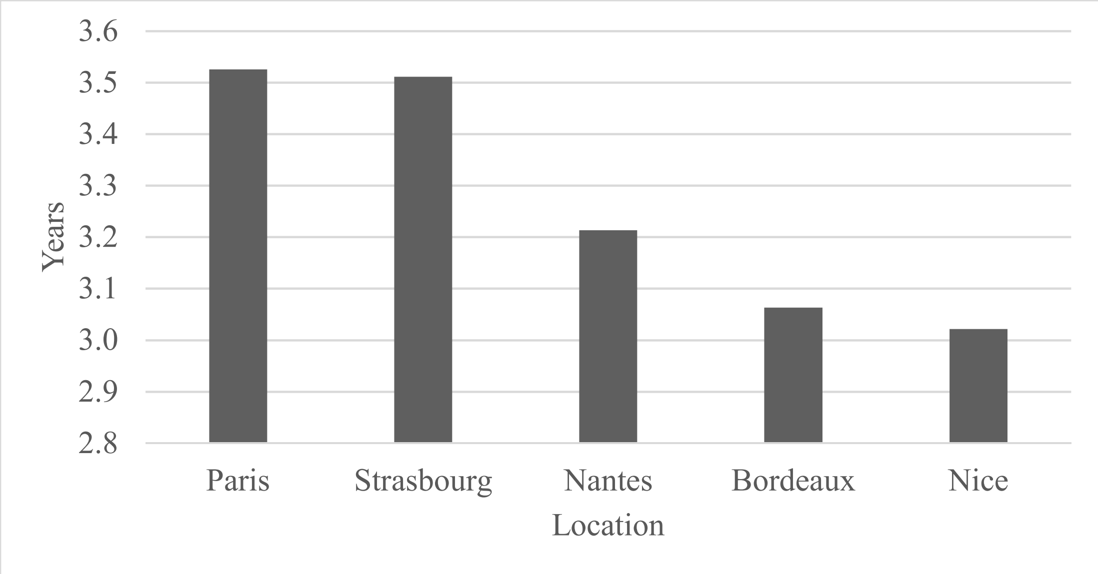

Figure 157: Payback period of the system

As presented in Figure 156, the highest net present value of the system is observed in Nice with almost 4.100€. That makes the project more economical feasible in this location because of more energy production. In Figure 157, it is apparent that Nice has the lowest payback period that means where the economic benefits are higher, the payback period will be shorter.

Having concluded with the base case scenario for each location a number of parametric simulations is made in order to examine the influence of different inputs to system energy, solar fraction, net present value and payback period of the domestic solar hot water system. The first parametric analysis has as input the number of collectors taking into consideration 1, 2 and 3 collectors. In addition, the next parametric analysis has as input the solar tank volumes including 0,18 m^3, 0,2 m^3 and 0,22 m^3 while the other parametric has as input the inclinations for the solar collectors ranging from 30° to 60° in steps of 5°. Finally, the last parametric has as input the number of occupants considering 3, 4 and 5 occupants regarding their average daily hot water usage of 150 kg/day, 200 kg/day and 250 kg/day respectively.

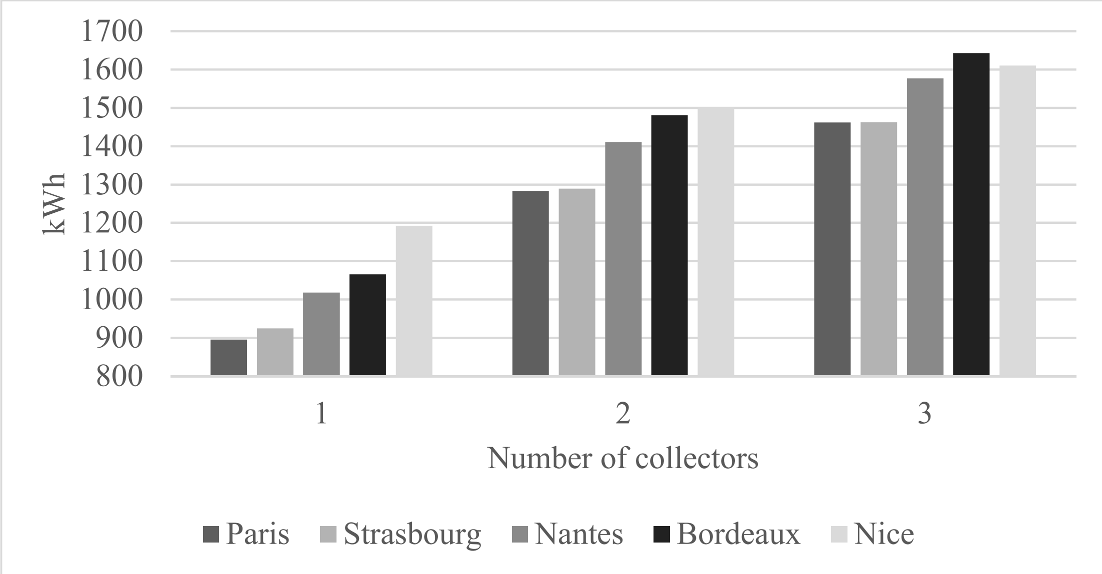

Figure 158: System energy for different collectors

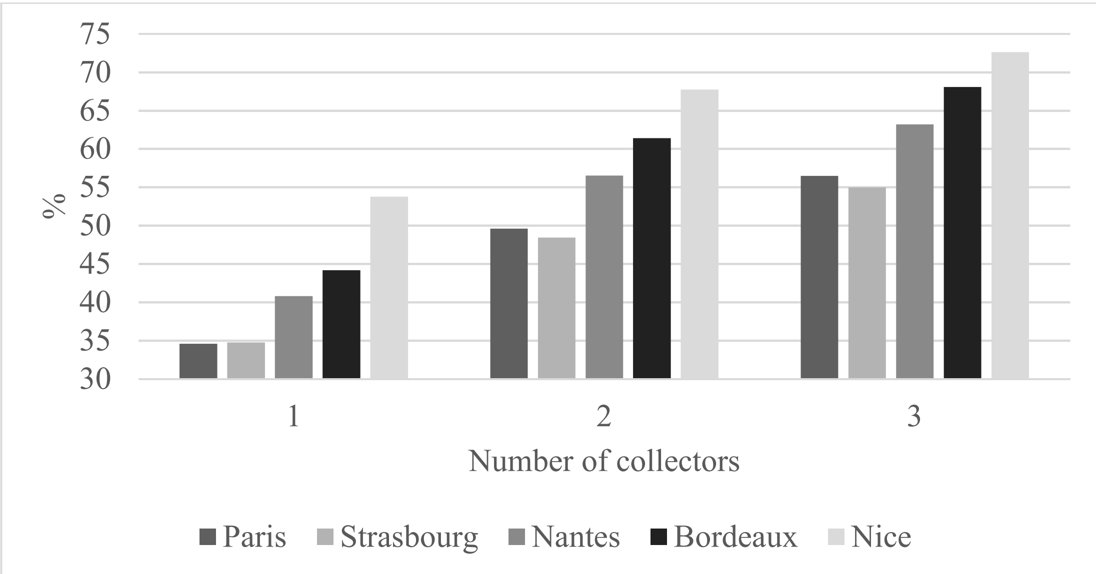

Figure 159: Solar fraction for different collectors

As presented in Figure 158, the system produces more energy as the number of collectors increases and Nice along with Bordeaux present the highest values with small differences in the case of 3 collectors. As shown in Figure 159, Nice presents the highest solar fraction in all cases with 54%, 68% and 72%. As the number of collectors increases, the solar fraction also does but not proportionately. Going from 1 collector to 2 collectors there is an increase of almost 14% but from 2 to 3 collectors the increase is 4%. During the summer months the energy demand is lower than the winter months. By having more than 2 collectors solar fraction will have a small increase since the energy produced by the system may increase but the demand is less than the winter months.

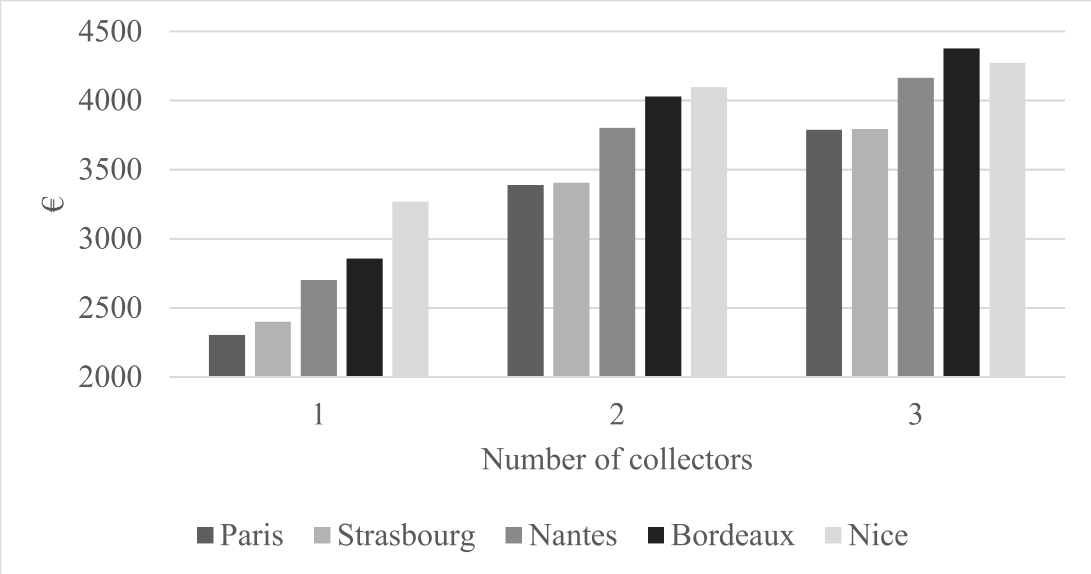

Figure 160: Net present value for different collectors

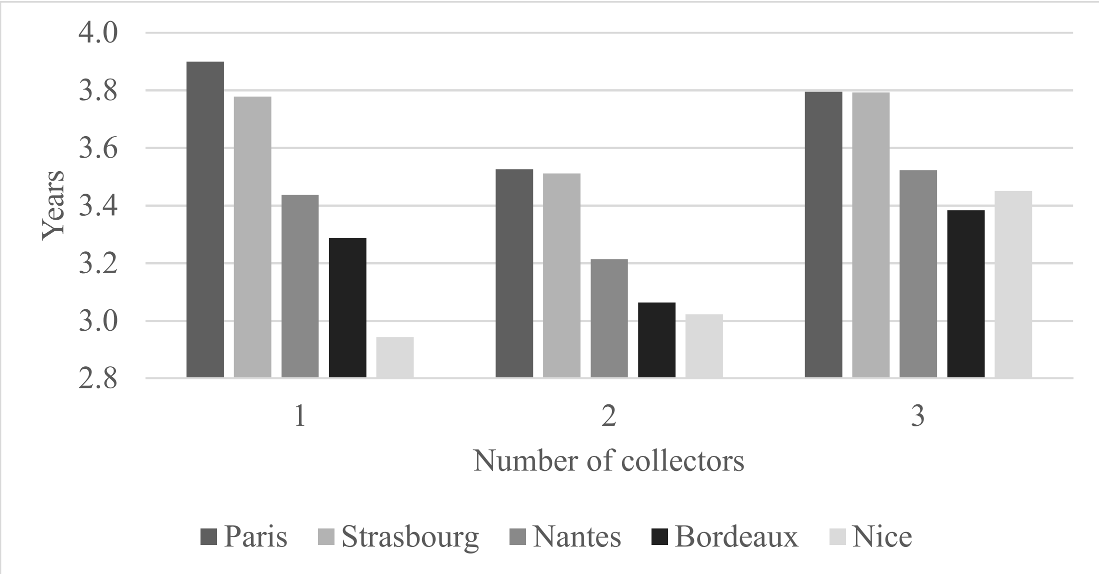

Figure 161: Payback period for different collectors

In Figure 160, the highest net present value is observed in Nice along with Bordeaux that makes the project more economical feasible in the case of 3 collectors where the most energy is produced. From Figure 161, it is apparent that the shortest payback period is noticed in Nice in the case of 1 collector with almost 3 years. In the case of 3 collectors, Nice and Bordeaux present the shortest payback period with almost 3,4 years following the rational of where the economic benefit is higher, the payback period is shorter.

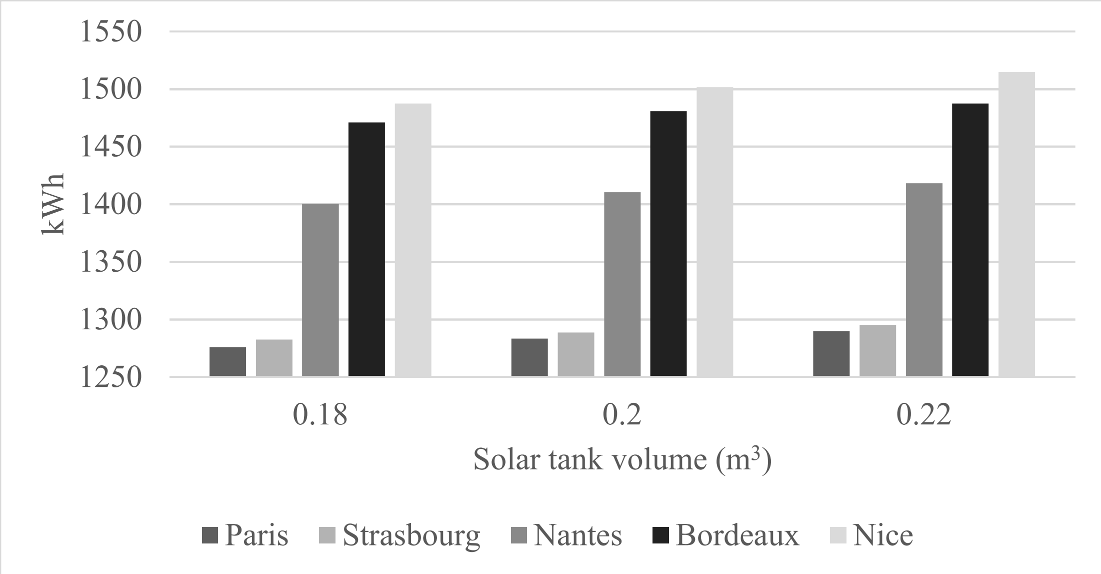

Figure 162: System energy for different solar tank volumes

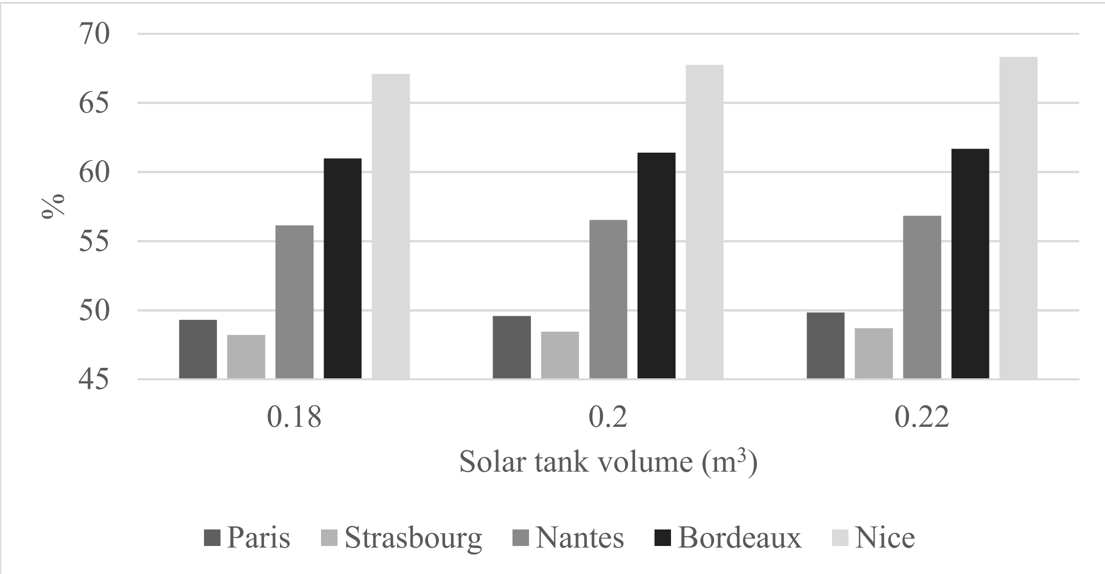

Figure 163: Solar fraction for different solar tank volumes

As shown in Figure 162, the energy produced by the system does not present large differences while the solar tank volume increases since the only thing that changes is the volume where water is stored with Nice presenting the highest values. As presented in Figure 163, Nice has the highest solar fractions ranging from 67% to 68% and that the increase in the solar tank volumes does not influence coverage as much because the difference among them is 0,02 m^3 and the energy input of the domestic solar hot water system has small changes.

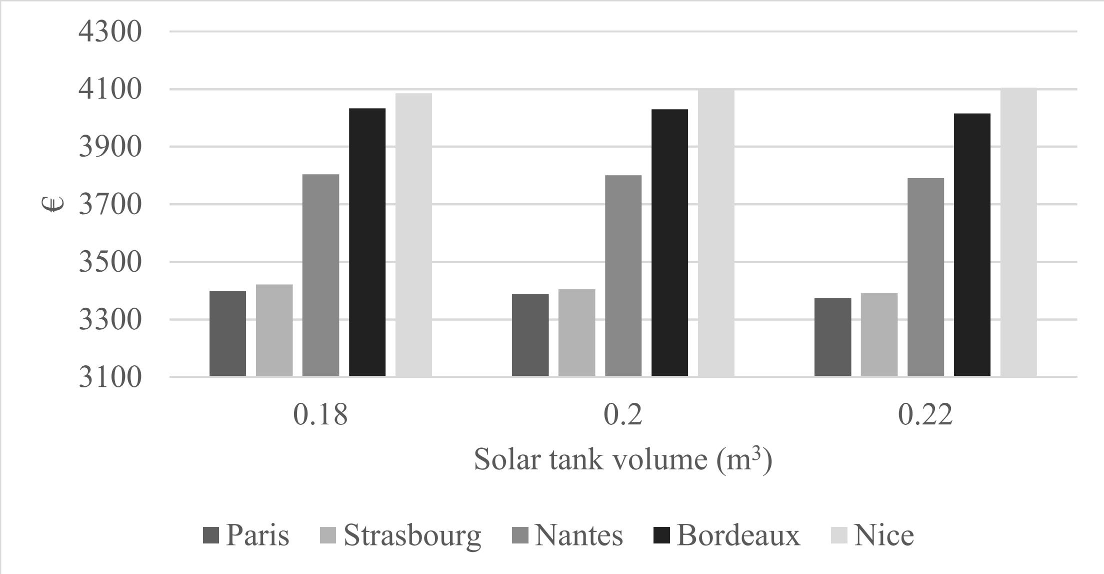

Figure 164: Net present value for different solar tank volumes

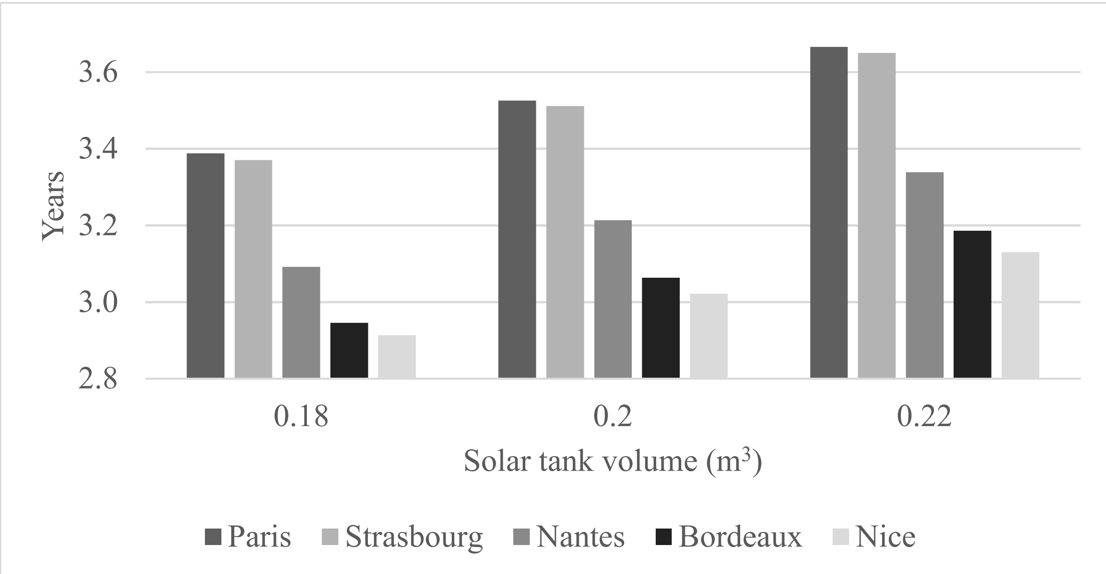

Figure 165: Payback period for different solar tank volumes

In Figure 164, the highest net present value is observed in Nice with small dissimilarities and that is why in Figure 165, Nice has also the lowest payback period without large differences.

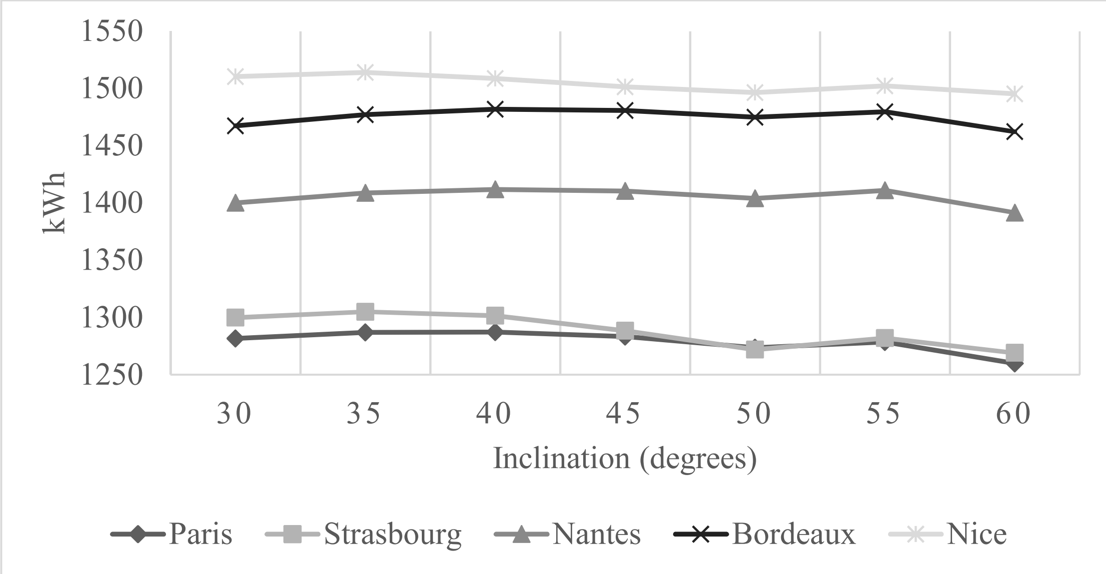

Figure 166: System energy for different inclinations

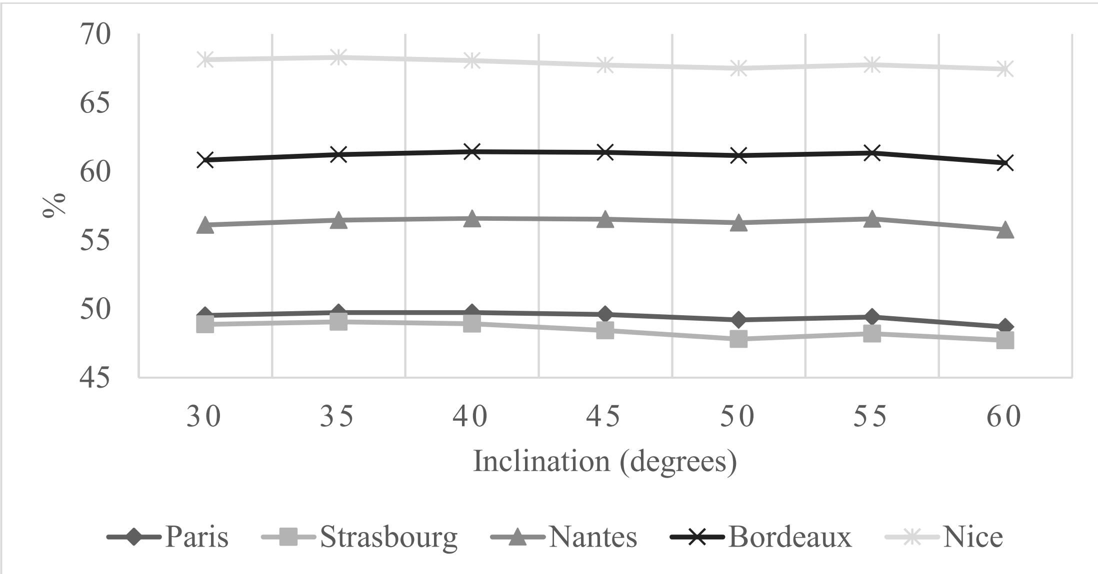

Figure 167: Solar fraction for different inclinations

In Figure 166, it is evident that the most energy is produced in Nice in the case of 35^{o} with 1.514 kWh while in Figure 167 the solar fraction is higher in Nice in 35^{o} with 68,3%. The domestic solar hot water system is producing more energy in Nice and the solar fraction is higher in Nice due to the fact that the energy demand in Nice is lower than the other locations. In all cases it is observed that after 40^{o} the solar fraction and the system energy are decreasing. The small increase that exists between 50^{o} and 55^{o} is because of the solar gains that the system may have during some winter months.

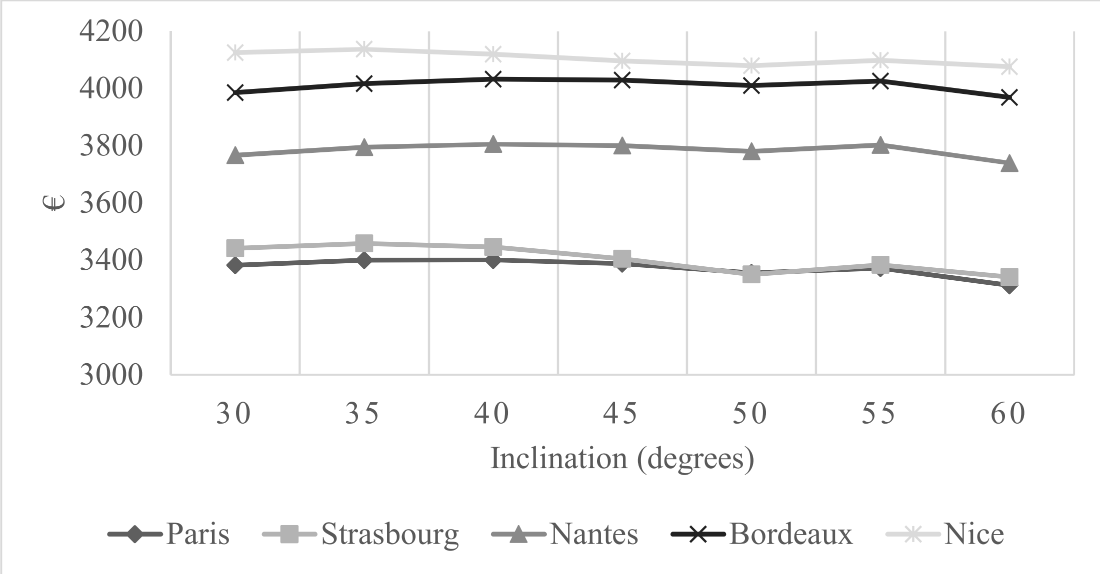

Figure 168: Net present value for different inclinations

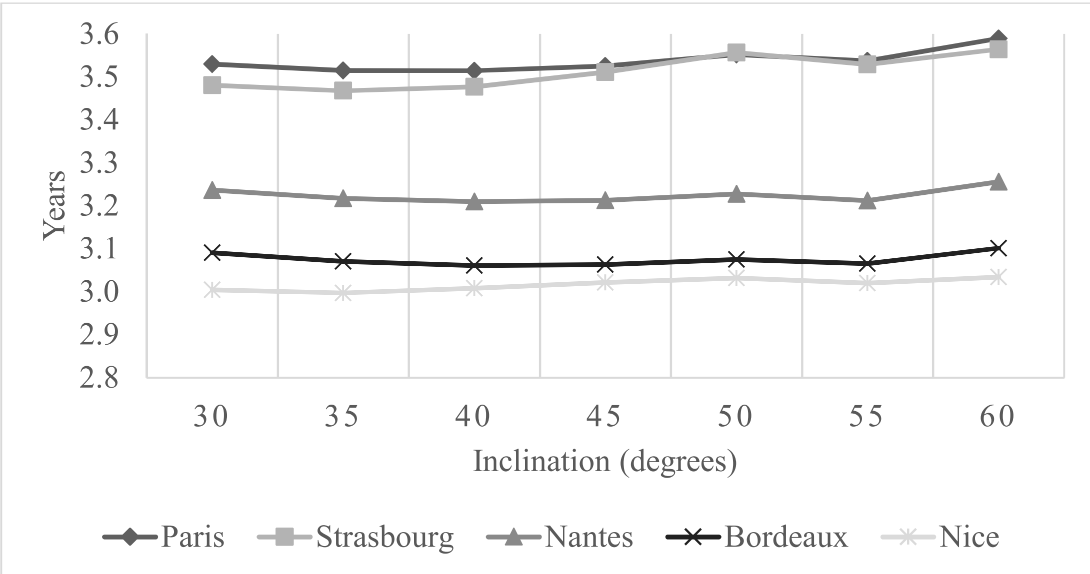

Figure 169: Payback period for different inclinations

In Figure 168, it is apparent that Nice presents the highest net present value noticed in 35º with 4.137€ making the project more economically feasible and in Figure 169, the lowest payback period is in Nice in the case of 35º with 3 years because of where the economic benefit is higher the payback period will be shorter.

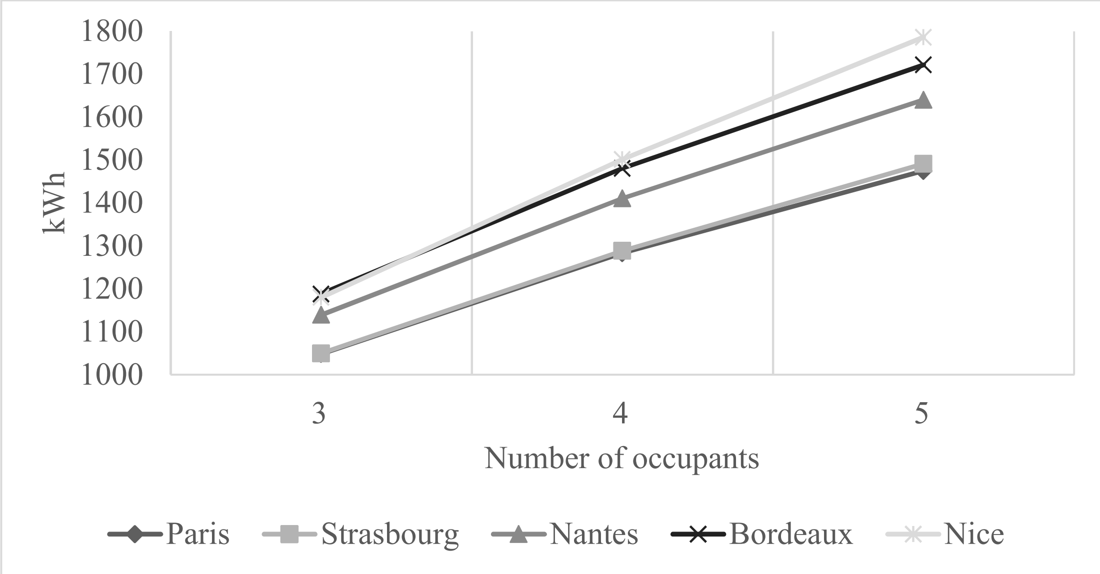

Figure 170: System energy for different occupants

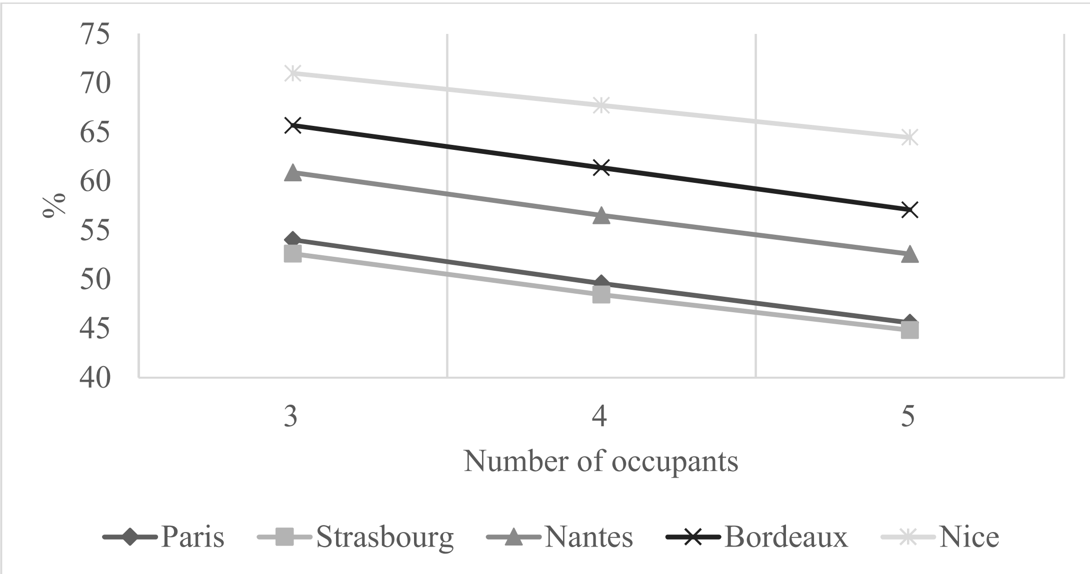

Figure 171: Solar fraction for different occupants

In Figure 170, it is evident that the most energy is produced in Nice for 5 occupants reaching almost 1.800 kWh. Some solar gains that the domestic solar hot water system has during summer months may not be used and are lost. As the number of occupants increases, their energy demand also increases and these extra solar gains that were not previously used are in favor to cover the occupants' needs. In Figure 171, solar fraction presents a decrease as the number of occupants increases. Nice has the highest solar fraction observed for 3 occupants being 71% and their average hot water usage equals to 150 kg/day. Despite the fact that the energy produced by the system is increasing, the energy demand is higher and as a result the solar fraction is diminishing.

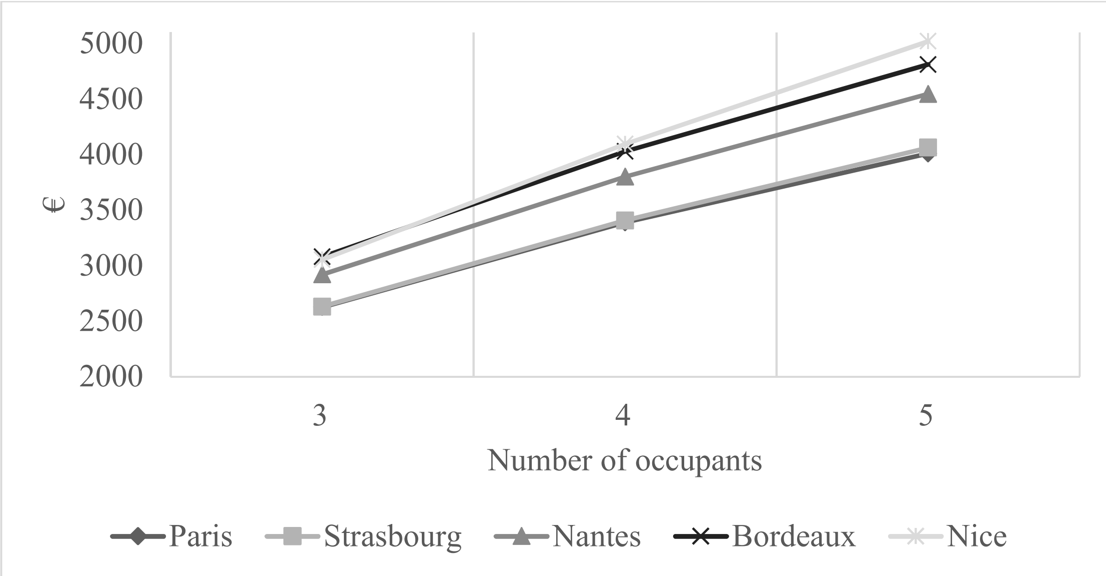

Figure 172: Net present value for different occupants

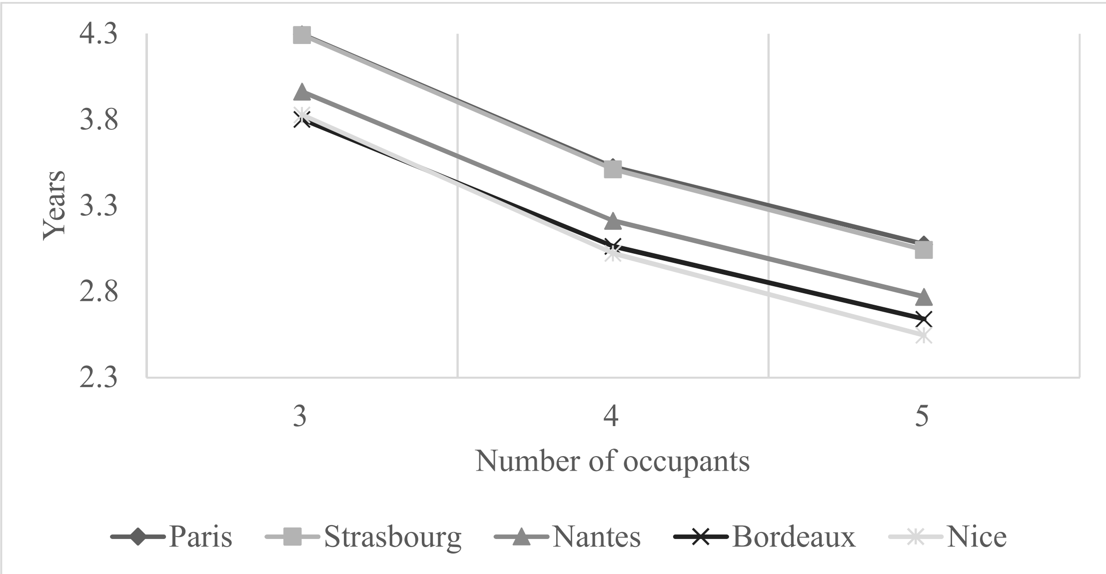

Figure 173: Payback period for different occupants

As shown in Figure 172, Nice has the highest net present value observed at 5.021€ in for 5 occupants. That makes the project more economically feasible since the energy produced by the system in this case is the highest one. In Figure 173, the payback period is lowest in Nice for 5 occupants for almost 2,6 years which is in accordance to where there are large economic benefits, the payback period will be shorter.

It can be concluded that among the five locations of France, the base case scenario (4 occupants, collector area= 4 m^2, $F_R(\tau\alpha)$= 0,76, F_RU_L= 4,5 W/m^2 C, inclination= 45^o) presents better performance in Nice in all aspects. In the first parametric analysis, the system produces more energy in Nice and Bordeaux in the case of 3 collectors and they also have the highest net present value. Regarding solar fraction, Nice in the case of 3 collectors has the highest one and in general as the number of collectors increases, the solar fraction also increases but not with the same rate mainly because of the different energy demand during summer and winter months. The payback period is shorter in Nice and Bordeaux in the case of 1 collector without large differences. Furthermore, the next parametric analysis showed that for system energy Nice presented the highest one in 0,22 m^3. Additionally, the parametric analysis having as input the inclination of the system showed that Nice had the best results in 35^o regarding all aspects. Nice is located at North East France and has a hot summer Mediterranean climate with mild winters and hot and dry summers. Between 50^o and 55^o there is a small increase because of some potential solar earnings the system may have during winter months. Finally, in the parametric analysis for the number of occupants, Nice presented the highest value for 5 occupants in system energy. As the number of occupants increases, the system takes advantage of the solar gains which in other cases (3 or 4 occupants) are lost and raises its energy production. It has the highest solar fraction for 3 occupants. Even if the domestic solar hot water system produces more energy for 5 occupants, the energy demand for them remains higher. It is reasonable since the less the number of people and their average daily hot water usage of 150 kg/day, the domestic solar hot water system can provide more coverage for their needs. Nice has the highest net present value and lowest payback period for 5 occupants, following the essential of where the economic benefits are higher, the shorter is the payback period of the initial investment as electricity replacement.

Having calculated the solar fraction for various household types in five locations in France, a rough estimation of the total energy conservation that the use of solar thermal systems has in France is performed. According to the French National Institute of Statistics and Economic Studies [69] the average size of a typical household consists of 3 occupants. The average solar fraction of the locations that corresponds to this number of occupants is 60,8% which means that the amount of energy saved annually from a domestic solar hot water system similar to the base case scenario results to 1.121 kWh per system. Taking into consideration the total glazed area of the country and the residential energy consumption [63], the total energy conservation for all systems in France during the last 11 years is estimated.

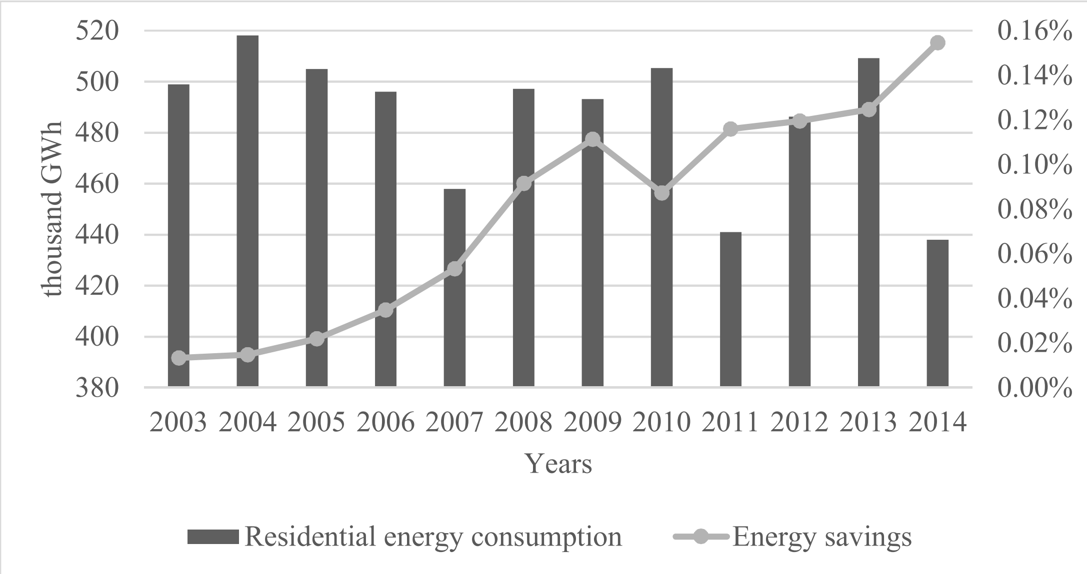

Figure 174: Total energy conservation

As presented in Figure 174, the total energy conservation increased during the last years as more systems were installed. It started with 66,5 GWh in 2003, a decrease in 2010 due to economic crisis and resulted to almost 677 GWh in 2014. Since 2004, energy consumption in the residential sector has started to decrease except for some increases. The reduction was influenced by economic performance, lower heat consumption due to better climatic conditions, more efficient electrical appliances and heating systems. In 2003, the potential energy savings deriving from the domestic solar hot water systems accounted for 0,01% of the total residential energy consumption. These savings reached to 0,15% of the total residential energy consumption in France in 2014.

In order to estimate the emissions reduction of GHG because of the domestic solar hot water systems usage, the emission factors for France per kWh of electricity generated were taken into consideration [64].

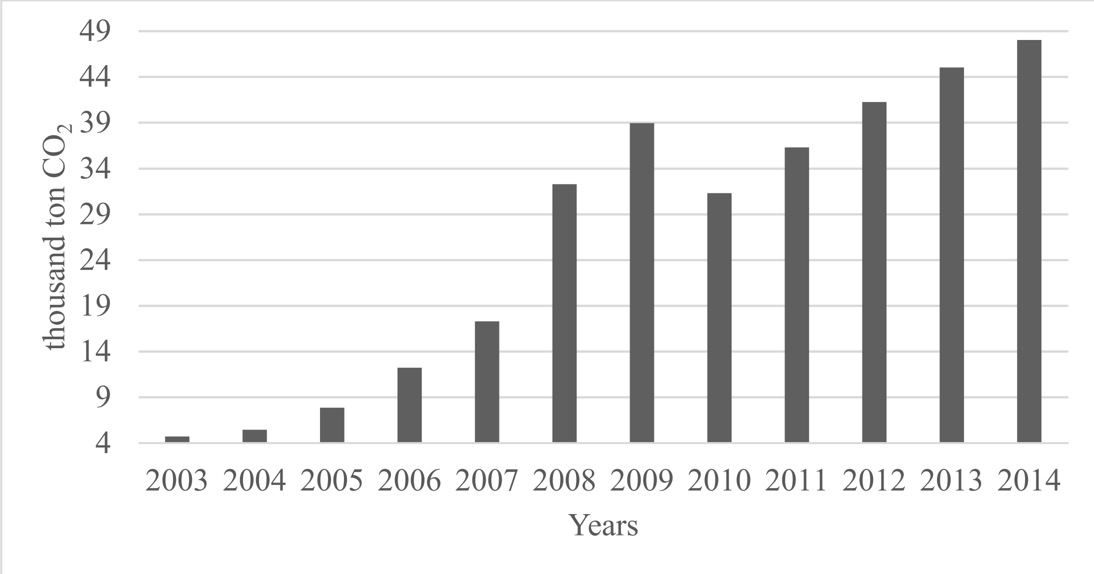

Figure 175: Tons of CO_2 saved

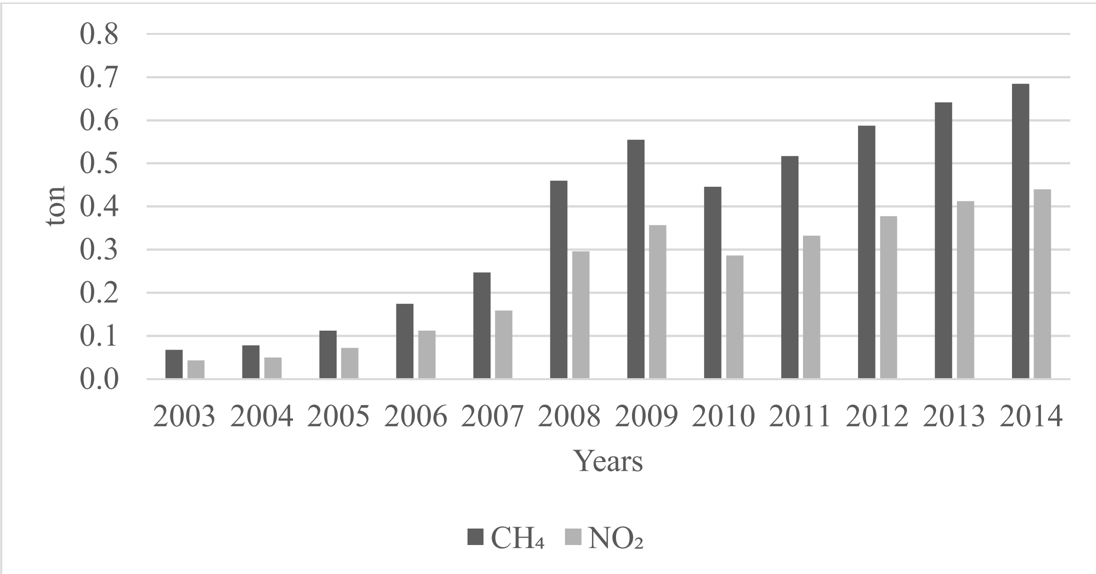

Figure 176: Tons of CH_4 and NO_2 saved

As presented in Figure 175, there was a steady increase for thousand tons of CO_2 saved by the domestic solar hot water systems usage from 2003 to 2014 except a small decrease in 2010. It started with 4,7 thousand tons in 2003 and reached 48 thousand tons in 2014. The same happened with CH_4 and NO_2, as presented in Figure 176, that started with 0,07 and 0,04 tons in 2003 and reached 0,7 and 0,4 tons in 2014 respectively.

4.7. POLAND

The locations examined for Poland are the metropolitan area of Kolobrzeg in Northern Poland and the capital Warsaw in Central Poland in order to cover all the different climatic conditions and for which full meteorological data in TMY format were available.

Table 9: Coordinates and elevation of locations

Location	Latitude	Longitude	Elevation
Kolobrzeg	54,18^o	15,58^o	5 m
Warsaw	52,17^o	20,97^o	107 m

The latitude, longitude and elevation of each location are presented in Table 9. The electricity rate for Poland, incorporating all taxes and energy prices, is 0,142 €/kWh [60]. The inclination is set at 50^o and the inflation rate is set at 1%/year [40, 72]. The average daily hot water usage is 50 kg/day/person and the solar tank has a volume of 0,2 m^3.

Figure 177: System energy

Figure 178: Solar fraction of the system

In Figure 177, it is evident that the highest amount of energy is produced in Kolobrzeg with almost 1.332 kWh without large difference from Warsaw. In Figure 178, it is shown that the solar fraction in Kolobrzeg is the largest with 47,3% without large difference from Warsaw. Kolobrzeg has lower energy demand than Warsaw.

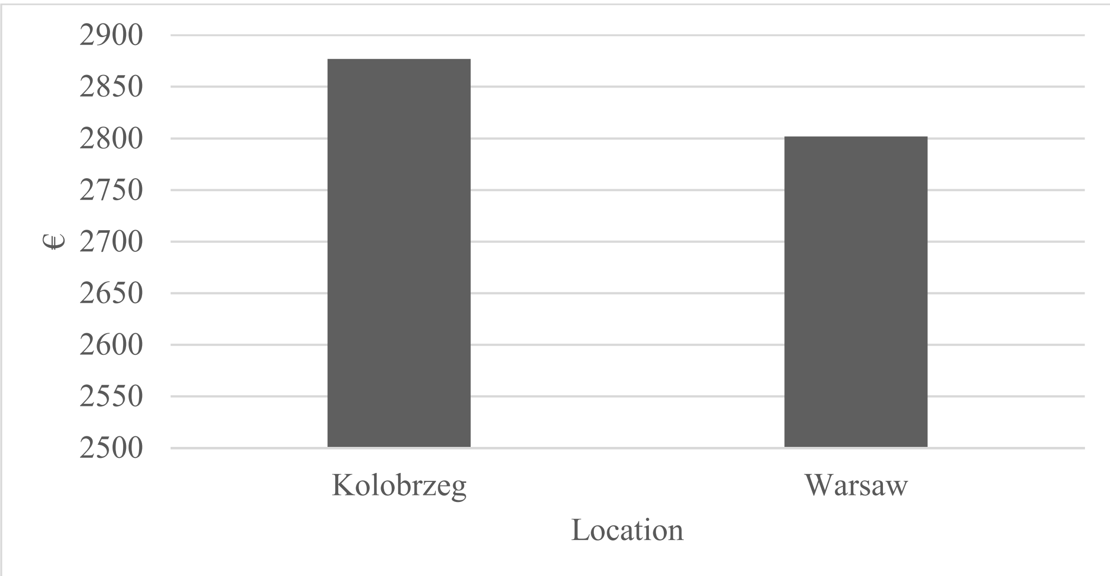

Figure 179: Net present value of the system

Figure 180: Payback period of the system

As presented in Figure 179, the highest net present value of the system is observed in Kolobrzeg with almost 2.877€ without large difference from Warsaw. In Figure 180, it is apparent that Kolobrzeg has the lowest payback period of 4 years without large difference from Warsaw which is in accordance to where the economic benefits are higher the payback period will be shorter.

Having concluded with the base case scenario for each location a number of parametric simulations is made in order to examine the influence of different inputs to system energy, solar fraction, net present value and payback period of the domestic solar hot water system. The first parametric analysis has as input the number of collectors taking into consideration 1, 2 and 3 collectors. In addition, the next parametric analysis has as input the solar tank volumes including 0,18 m^3, 0,2 m^3 and 0,22 m^3 while the other parametric has as input the inclinations for the solar collectors ranging from 35° to 65° in steps of 5°. Finally, the last parametric has as input the number of occupants considering 3, 4 and 5 occupants regarding their average daily hot water usage of 150 kg/day, 200 kg/day and 250 kg/day respectively.

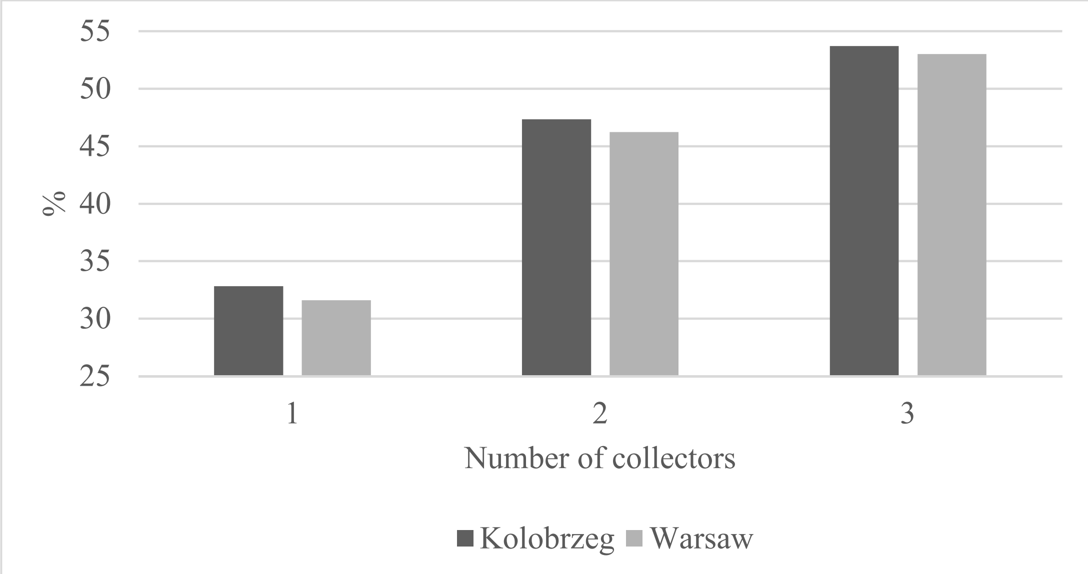

Figure 181: Solar fraction for different collectors

As shown in Figure 181, Kolobrzeg presents the highest value by 53,7% with small difference from Warsaw. As the number of collectors increases, the solar fraction also does but not proportionately. Going from 1 collector to 2 collectors there is an increase of almost 14% but from 2 to 3 collectors the increase is 7%. During the summer months the energy demand is lower than the winter months. By having more than 2 collectors solar fraction will have a small increase since the energy produced by the system may increase but the demand is less than the winter months.

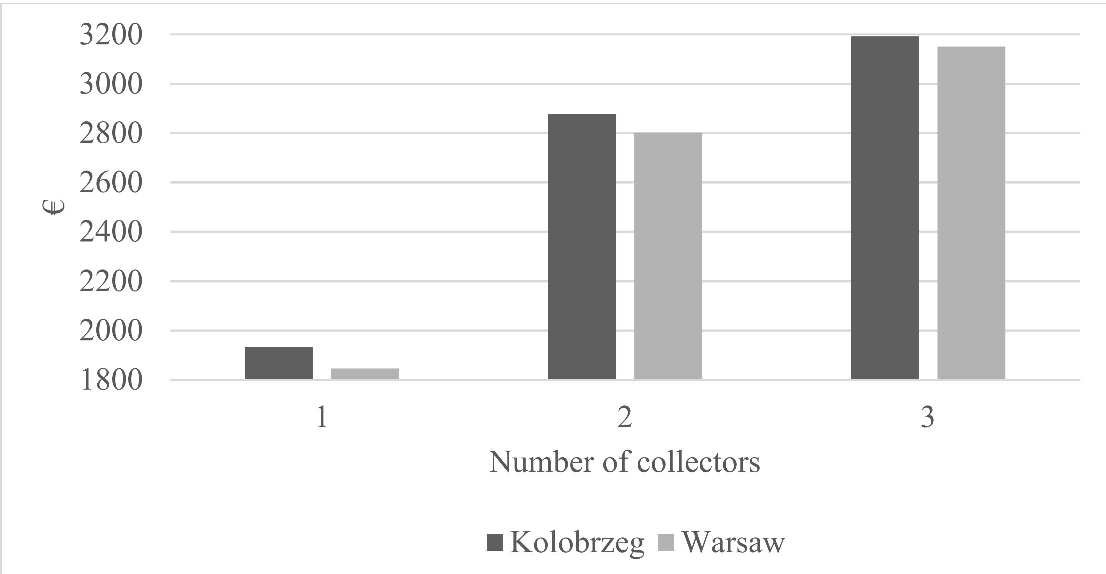

Figure 182: Net present value for different collectors

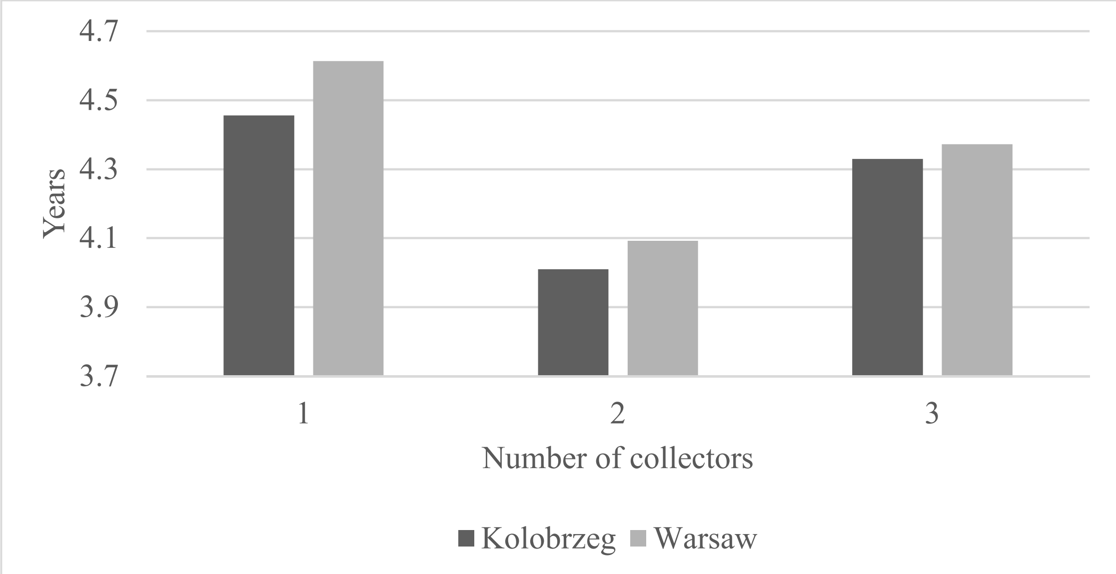

Figure 183: Payback period for different collectors

In Figure 182, the net present value in Kolobrzeg and in Warsaw are almost the same and the highest values are noticed in the case of 3 collectors where the most energy is produced. From Figure 183, it is apparent that the shortest payback period is noticed in the case of 2 collectors both for Kolobrzeg and Warsaw with small changes.

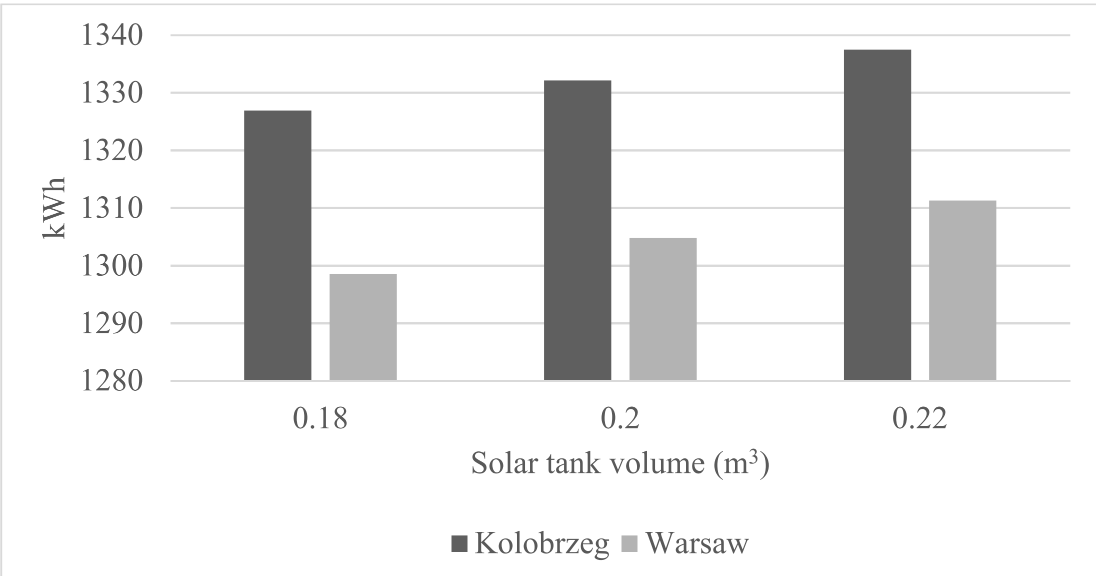

Figure 184: System energy for different solar tank volumes

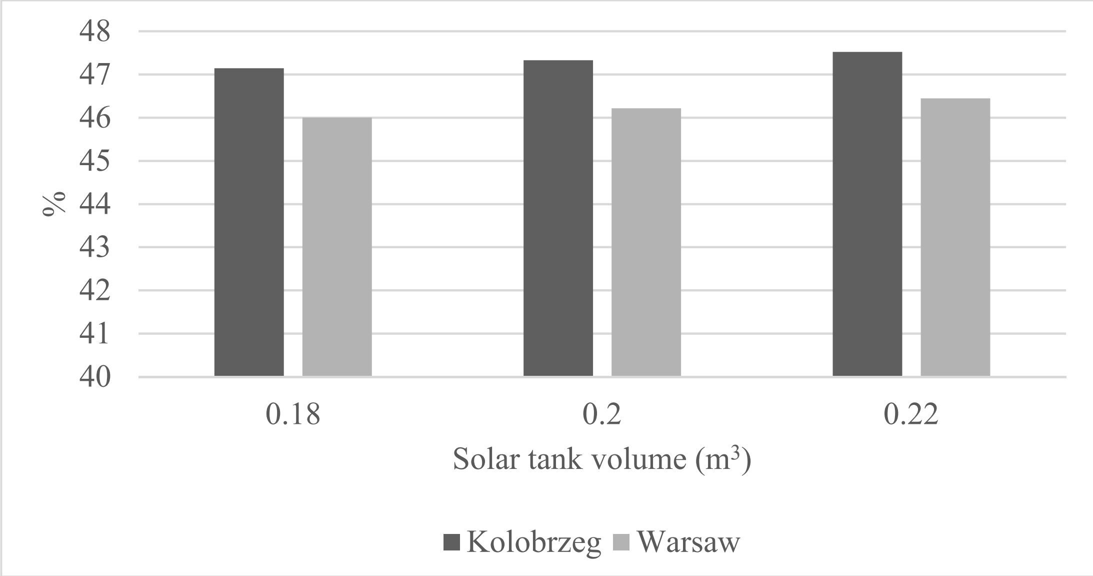

Figure 185: Solar fraction for different solar tank volumes

As shown in Figure 184, the energy produced by the system does not present large differences while the solar tank volume increases since the only thing that changes is the volume where water is stored. Kolobrzeg presents the highest value by 1.337 kWh in 0,22 m^3. As presented in Figure 185, Kolobrzeg has the highest solar fractions with and that the increase in the solar tank volumes does not influence coverage as much because the difference among them is 0,02 m^3 and the energy input of the domestic solar hot water system has small changes.

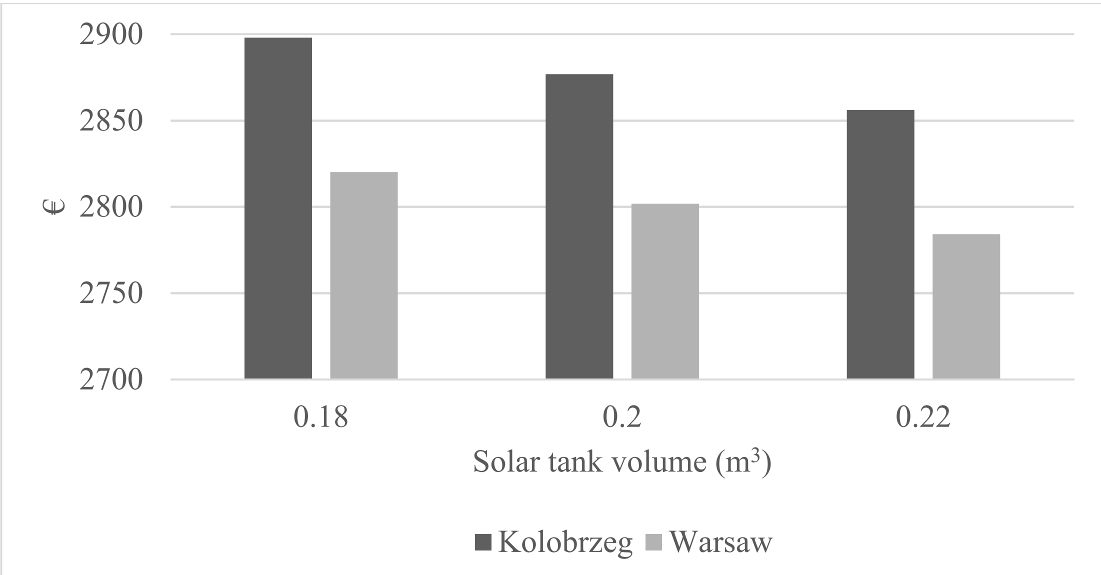

Figure 186: Net present value for different solar tank volumes

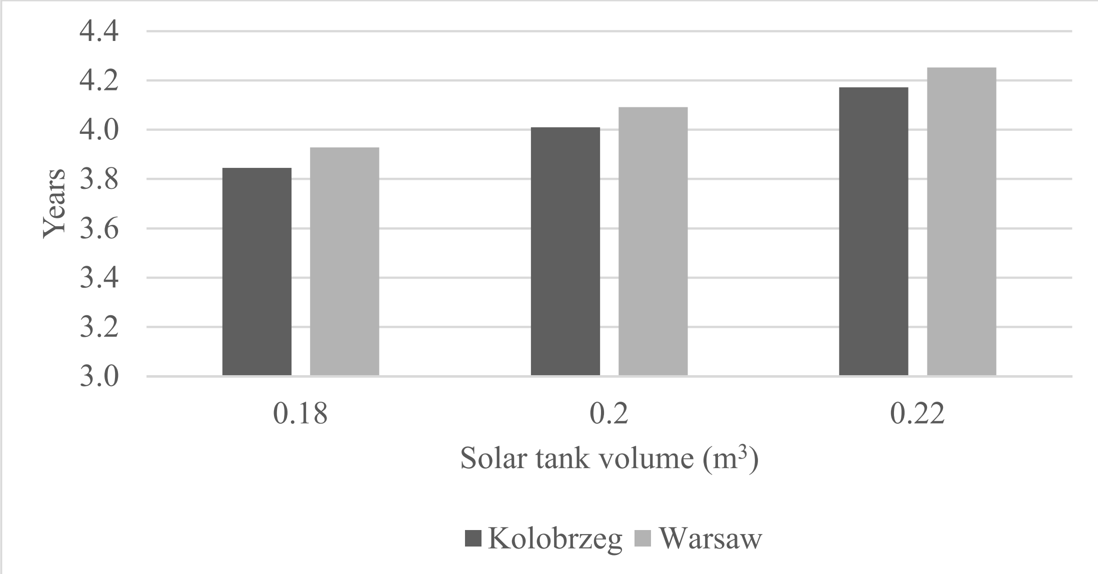

Figure 187: Payback period for different solar tank volumes

In Figure 186, the highest net present value is observed in Kolobrzeg with small dissimilarities and that is why in Figure 187, Kolobrzeg has also the lowest payback period without large differences.

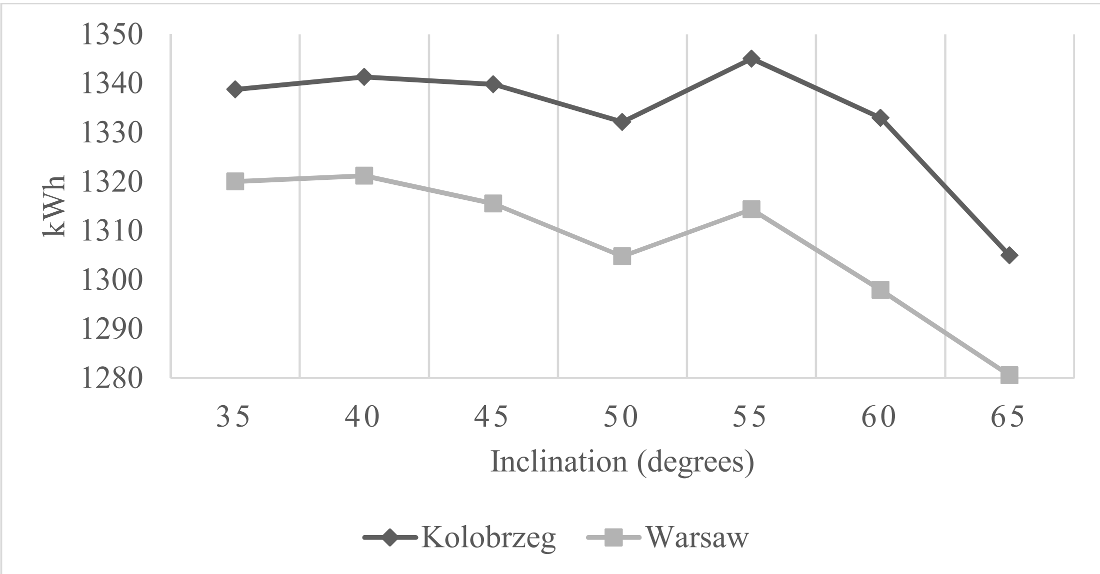

Figure 188: System energy for different inclinations

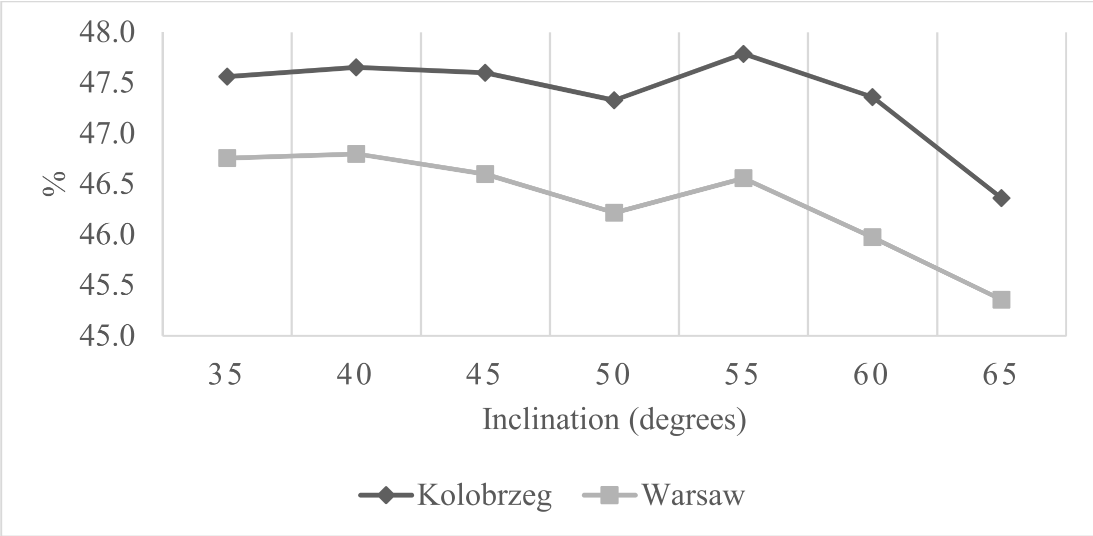

Figure 189: Solar fraction for different inclinations

In Figure 188, it is apparent that the most energy is produced in Kolobrzeg in the case of 55º with 1.345 kWh while in Figure 189 the solar fraction is higher in Kolobrzeg in 55º with 47,8%. The domestic solar hot water system is producing more energy in Kolobrzeg and the solar fraction is also higher in Kolobrzeg due to the fact that the energy demand is lower than it is in Warsaw. In all cases it is observed that after 55º the solar fraction and the system energy are decreasing. The small increase that exists between 50º and 55º is because of the solar gains that the system may have during some winter months.

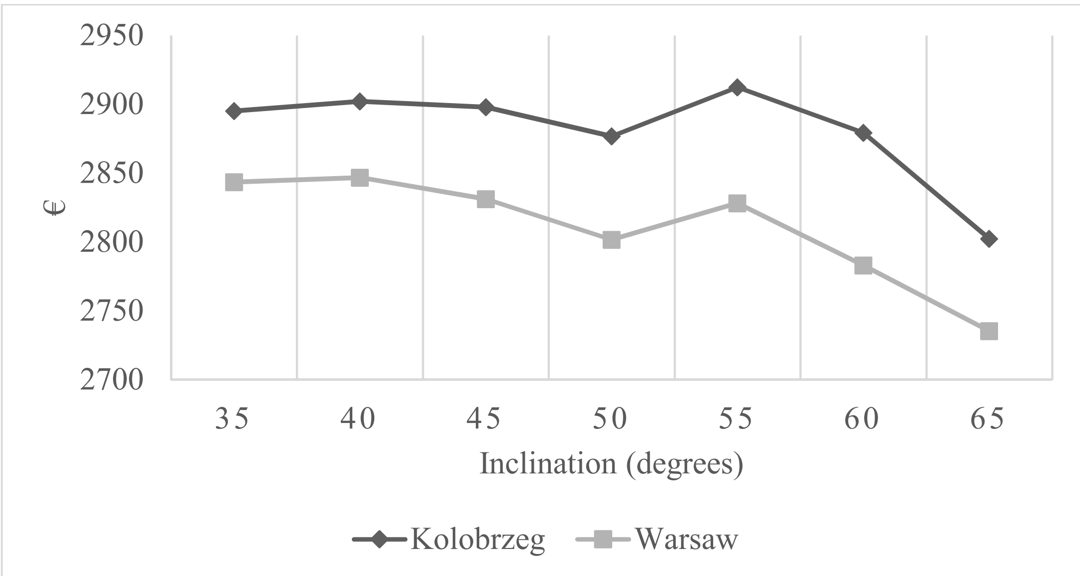

Figure 190: Net present value for different inclinations

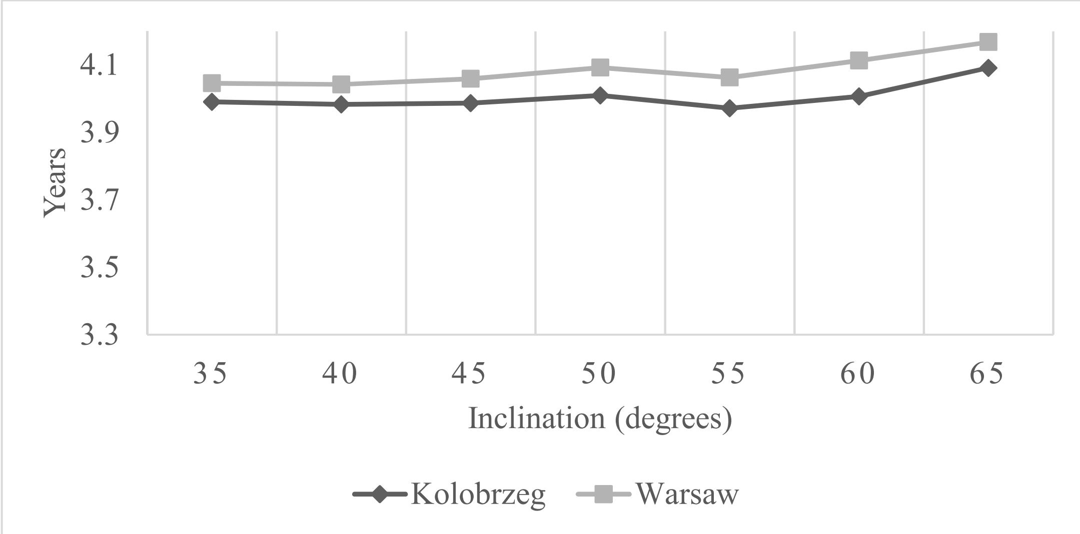

Figure 191: Payback period for different inclinations

In Figure 190, it is apparent that Kolobrzeg presents the highest net present value noticed in 55º with 2.912€ making the project more economically feasible and in Figure 191, the lowest payback period is in Kolobrzeg in the case of 55º with almost 4 years for the reason that where the economic benefit is higher the payback period will be shorter.

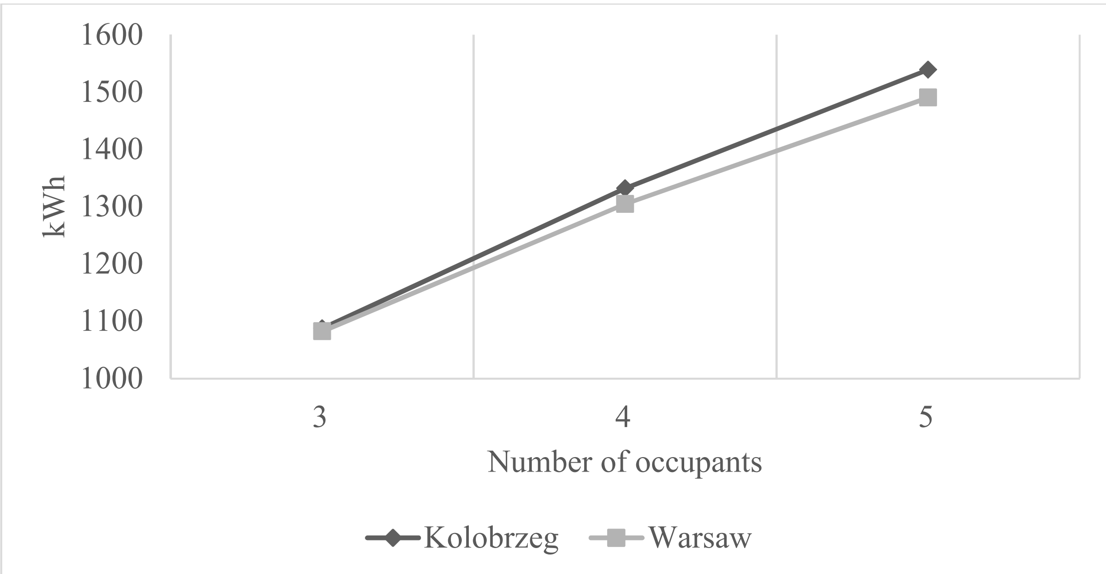

Figure 192: System energy for different occupants

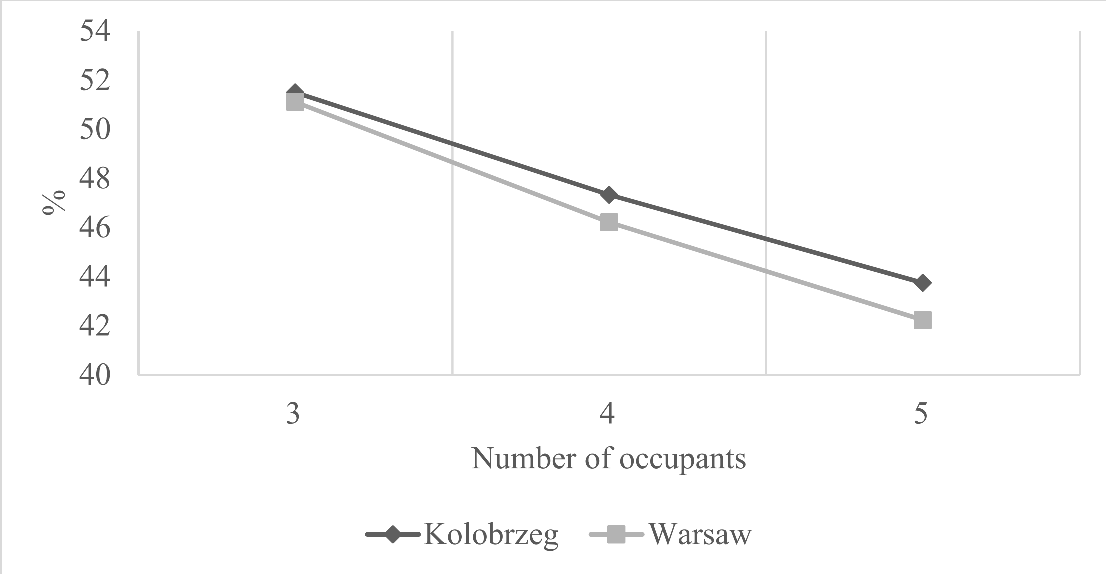

Figure 193: Solar fraction for different occupants

In Figure 192, it is evident that the most energy is produced in Kolobrzeg for 5 occupants reaching 1.539 kWh. Some solar gains that the domestic solar hot water system has during summer months may not be used and are lost. As the number of occupants increases, their energy demand also increases and these extra solar gains that were not previously used are in favor to cover the occupants' needs. In Figure 193, solar fraction presents a decrease as the number of occupants increases. Kolobrzeg has the highest solar fraction observed for 3 occupants being 51,5% with small diferrence from Warsaw and their average hot water usage equals to 150 kg/day. Despite the fact that the energy produced by the system is increasing, the energy demand is higher and as a result the solar fraction is diminishing.

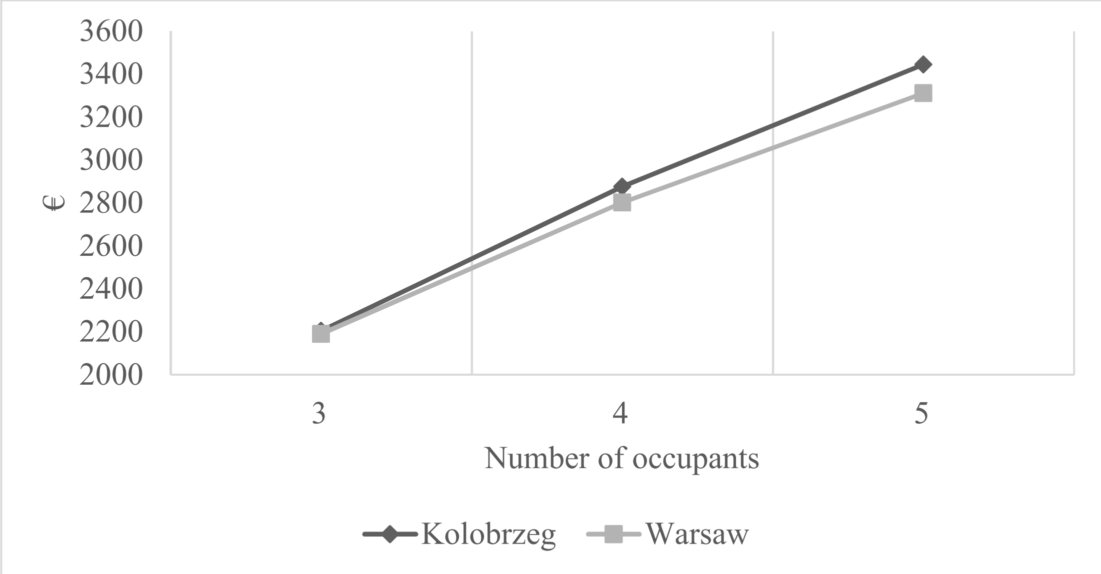

Figure 194: Net present value for different occupants

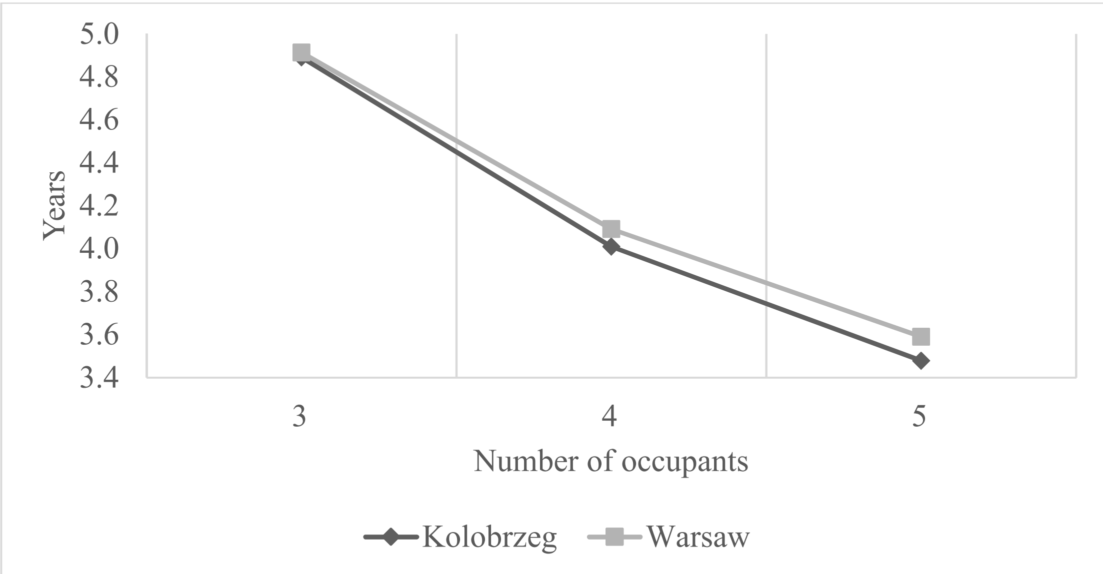

Figure 195: Payback period for different occupants

As shown in Figure 194, Kolobrzeg has the highest net present value observed at 3.445€ for 5 occupants with small dissimilarity from Warsaw. In Figure 195, the payback period is lowest in Kolobrzeg with small difference from Warsaw for 5 occupants for 3,5 years which is in accordance to where there are large economic benefits, the payback period will be shorter.

It can be concluded that among the two locations of Poland, the base case scenario (4 occupants, collector area= 4 m^2, $F_R(\tau\alpha)$= 0,76, F_RU_L= 4,5 W/m^2 C, inclination= 50^o) presents better performance in Kolobrzeg in all aspects with small difference from

Warsaw. In the first parametric analysis, the system produces more energy in Kolobrzeg in the case of 3 collectors and has also the largest solar fraction and the highest net present value. In general, as the number of collectors increases, the solar fraction also increases but not with the same rate mainly because of the different energy demand during summer and winter months. Regarding payback period, Kolobrzeg and Warsaw in the case of 2 collectors have the lowest ones. Furthermore, the next parametric analysis showed that for system energy Kolobrzeg presents the highest one in 0,22 m^3. Additionally, the parametric analysis having as input the inclination of the system showed that Kolobrzeg had the best results in 55^o regarding all aspects. Kolobrzeg is located at North West Poland and has an oceanic climate with cool summers and warm winters. Finally, in the parametric analysis for the number of occupants, Kolobrzeg presents the highest value for 5 occupants in system energy. As the number of occupants increases, the system takes advantage of the solar gains which in other cases (3 or 4 occupants) are lost and raises its energy production. It has the highest solar fraction for 3 occupants. Even if the domestic solar hot water system produces more energy for 5 occupants, the energy demand for them remains higher. It is reasonable since the less the number of people and their average daily hot water usage of 150 kg/day, the domestic solar hot water system can provide more coverage for their needs. Kolobrzeg has the highest net present value and lowest payback period for 5 occupants, following the essential of where the economic benefits are higher, the shorter is the payback period of the initial investment as electricity replacement.

Having calculated the solar fraction for various household types in two locations in Poland, a rough estimation of the total energy conservation that the use of solar thermal systems has in Poland is performed. According to the Central Statistical Office of Poland [70] the average size of a typical household consists of 3 occupants. The average solar fraction of the locations that corresponds to this number of occupants is 51,3% which means that the amount of energy saved annually from a domestic solar hot water system similar to the base case scenario results to 1.085 kWh per system. Taking into consideration the total glazed area of the country and the residential energy consumption [63], the total energy conservation for all systems in Poland during the last 10 years is estimated.

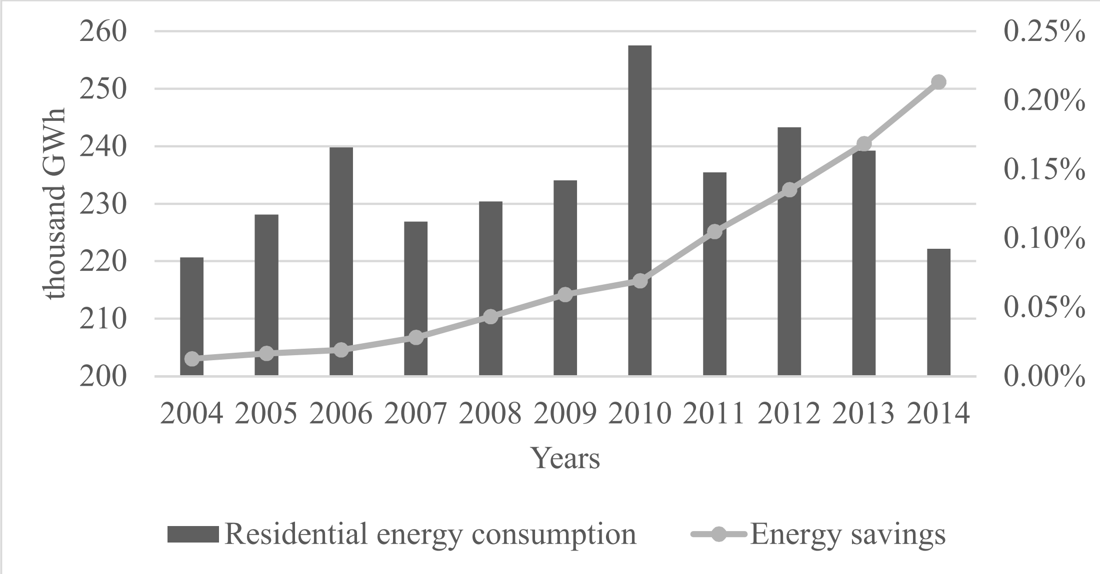

Figure 196: Total energy conservation

As presented in Figure 196, the total energy conservation increased during the last years as more systems were installed. It started with 28 GWh in 2004 and resulted to 473,5 GWh in 2014. Since 2006, energy consumption in the residential sector has started to decrease except for some increases like 2010 and 2012. The reduction was influenced by economic performance, lower heat consumption due to better climatic conditions, more efficient electrical appliances and heating systems. In 2004, the potential energy savings deriving from the domestic solar hot water systems accounted for 0,01% of the total residential energy consumption. These savings reached to 0,21% of the total residential energy consumption in Poland in 2014.

In order to estimate the emissions reduction of GHG because of the domestic solar hot water systems usage, the emission factors for Poland per kWh of electricity generated were taken into consideration [64].

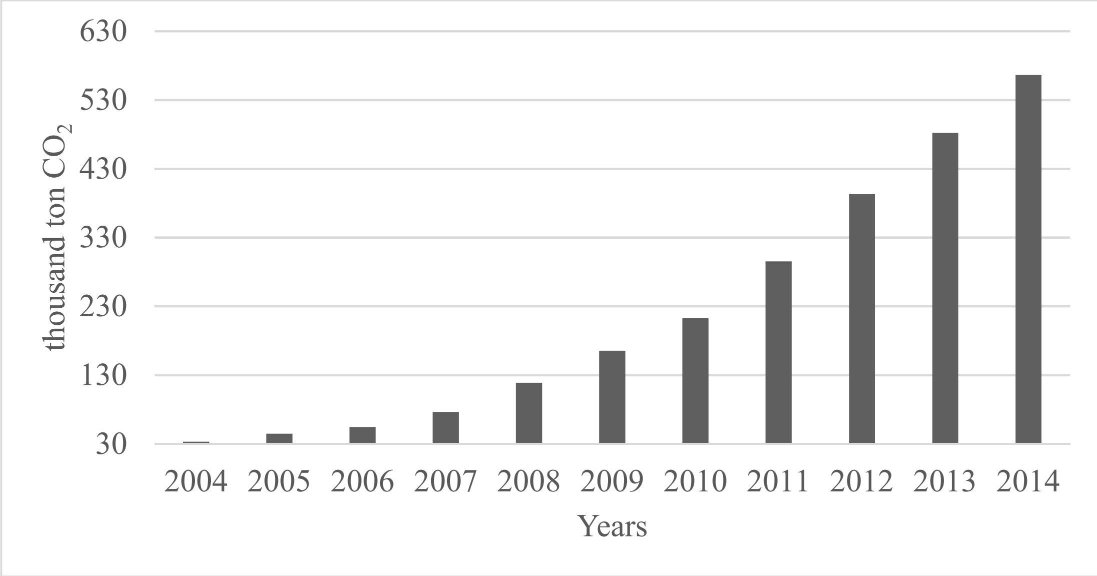

Figure 197: Tons of CO_2 saved

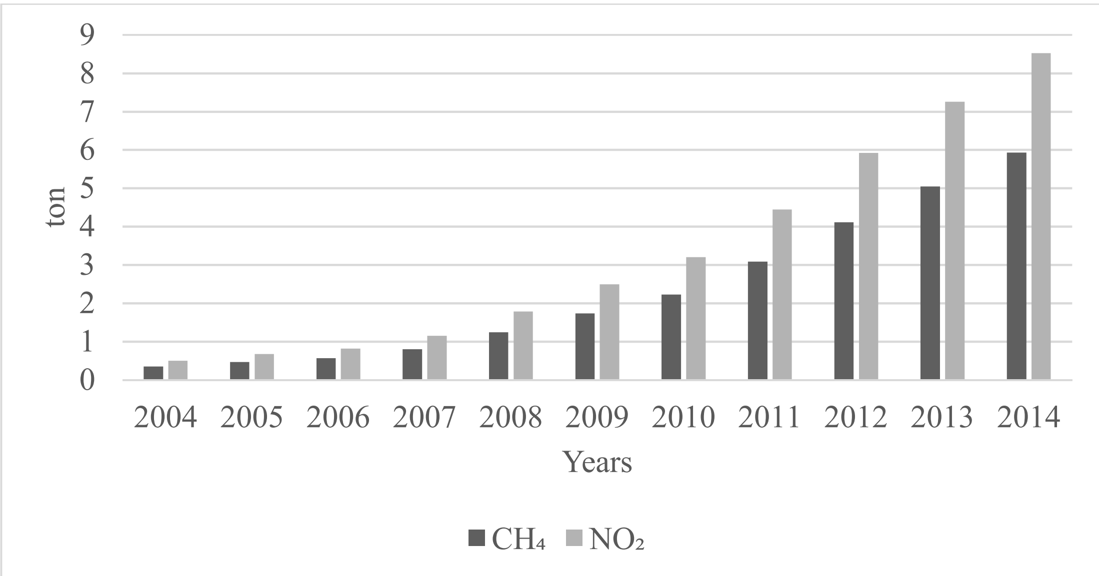

Figure 198: Tons of CH_4 and NO_2 saved

As presented in Figure 197, there was a steady increase for thousand tons of CO_2 saved by the domestic solar hot water systems usage from 2004 to 2014. It started with 33,3 thousand tons in 2004 and reached 566,4 thousand tons in 2014. The same happened with CH_4 and NO_2, as presented in Figure 198, that started with 0.35 and 0,5 tons in 2004 and reached almost 6 and 8,5 tons in 2014.

4.8. CYPRUS

The location examined for Cyprus is the metropolitan area of Larnaca in Eastern Cyprus for which full meteorological data in TMY format were available.

Table 10: Coordinates and elevation of location

Location	Latitude	Longitude	Elevation
Larnaca	34,88°	33,63°	2 m

The latitude, longitude and elevation of the location is presented in Table 10. The electricity rate for Cyprus, incorporating all taxes and energy prices, is 0,184 €/kWh [60]. The inclination is set at 35° and the inflation rate is set at 1%/year [40, 72]. The average daily hot water usage is 50 kg/day/person and the solar tank has a volume of 0,2 m^3.

Table 11: System simulation

Location	System energy (kWh)	Solar fraction (%)	Net present value (€)	Payback period (years)
Larnaca	1466,68	77,57	4436,96	2,8

As presented in Table 11, the base case scenario produces almost 1.467 kWh with solar fraction of 77,6%, the net present value is 4.437€ and the payback period reaches 2,8 years.

Having concluded with the base case scenario for the location a number of parametric simulations is made in order to examine the influence of different inputs to system energy, solar fraction, net present value and payback period of the domestic solar hot water system. The first parametric analysis has as input the number of collectors taking into consideration 1, 2 and 3 collectors. In addition, the next parametric analysis has as input the solar tank volumes including 0,18 m^3, 0,2 m^3 and 0,22 m^3 while the other parametric has as input the inclinations for the solar collectors ranging from 20° to 50° in steps of 5°. Finally, the last parametric has as input the number of occupants considering 3, 4 and 5 occupants regarding their average daily hot water usage of 150 kg/day, 200 kg/day and 250 kg/day respectively.

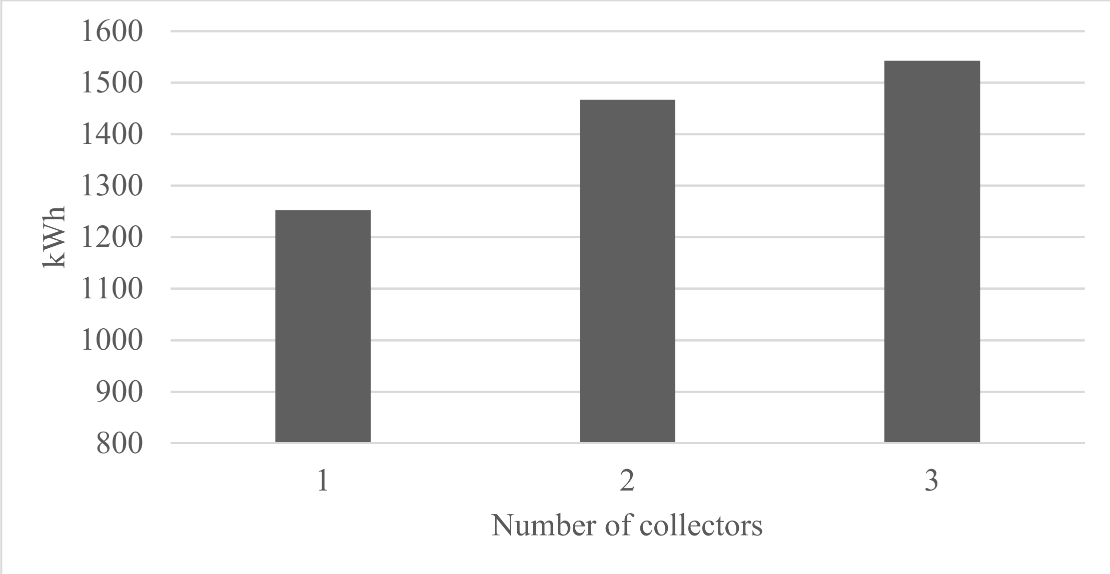

Figure 199: System energy for different collectors

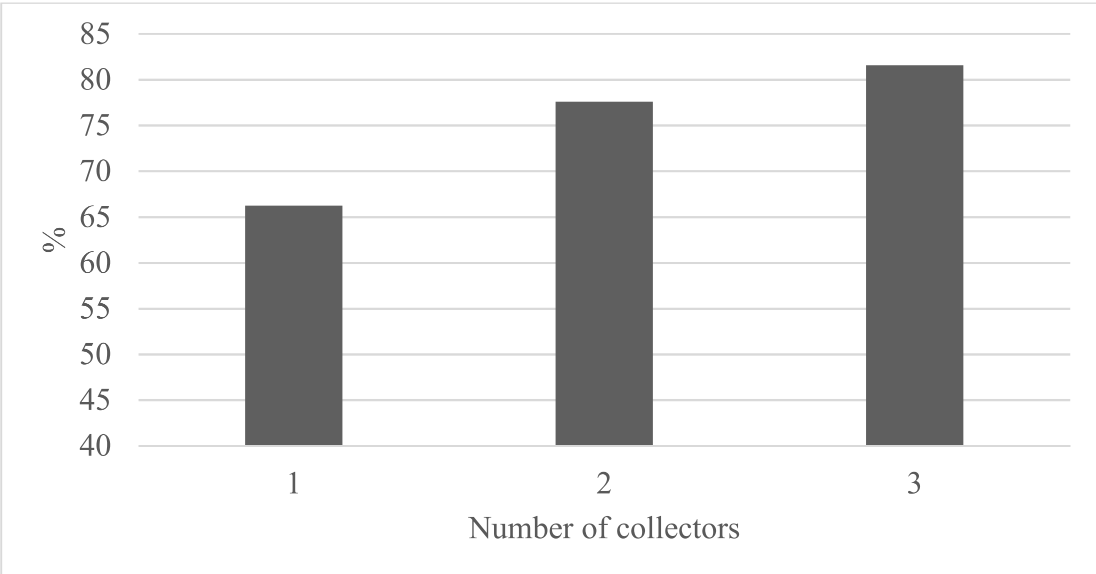

Figure 200: Solar fraction for different collectors

As presented in Figure 199, the system produces more energy as the number of collectors increases and especially in the case of 3 collectors with 1.542 kWh. As shown in Figure 200, the highest solar fraction is in the case of 3 collectors with 81,6%. While the number of collectors increases, the solar fraction also does but not proportionately. Going from 1 collector to 2 collectors there is an increase of almost 12% but from 2 to 3 collectors the increase is 5%. During the summer months the energy demand is lower than the winter months. By having more than 2 collectors solar fraction will have a small increase since the energy produced by the system may increase but the demand is less than the winter months.

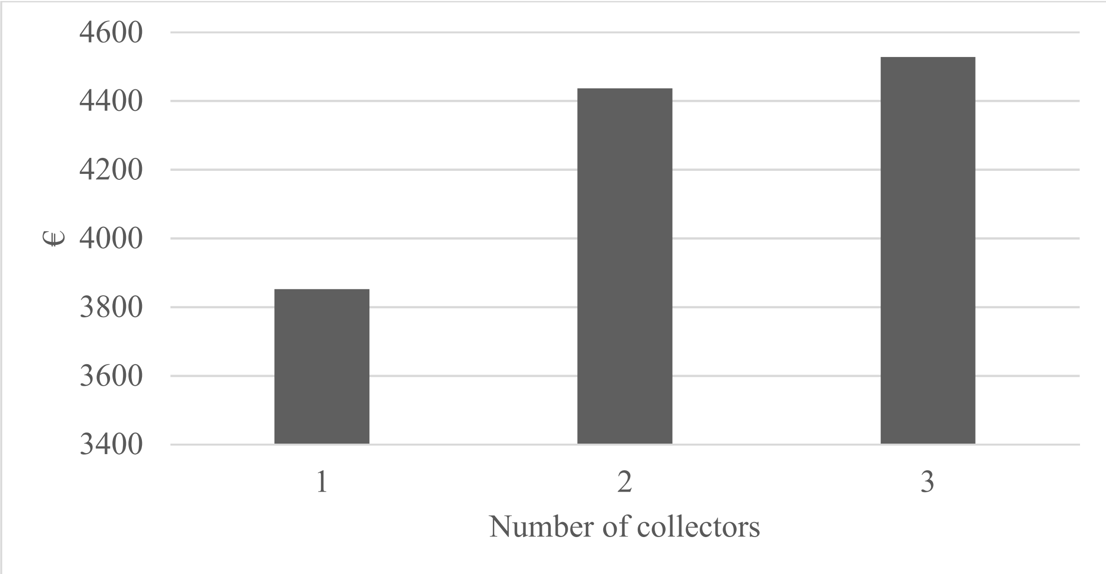

Figure 201: Net present value for different collectors

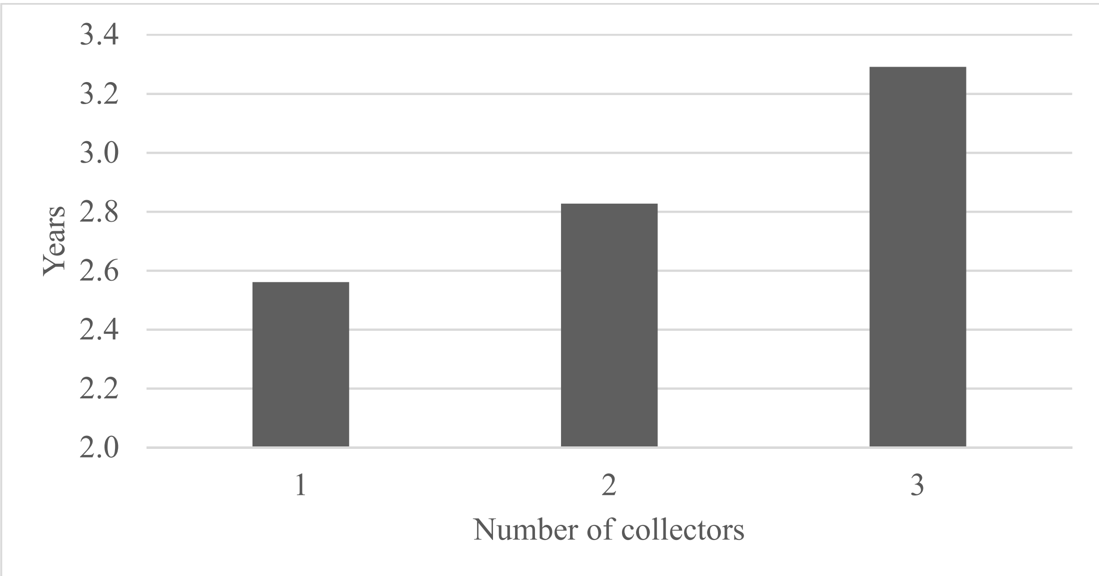

Figure 202: Payback period for different collectors

In Figure 201, the highest net present value is 4.528€ that makes the project more economical feasible in the case of 3 collectors where the most energy is produced. From Figure 202, it is apparent that the shortest payback period is noticed in the case of 1 collector with almost 2,6 years.

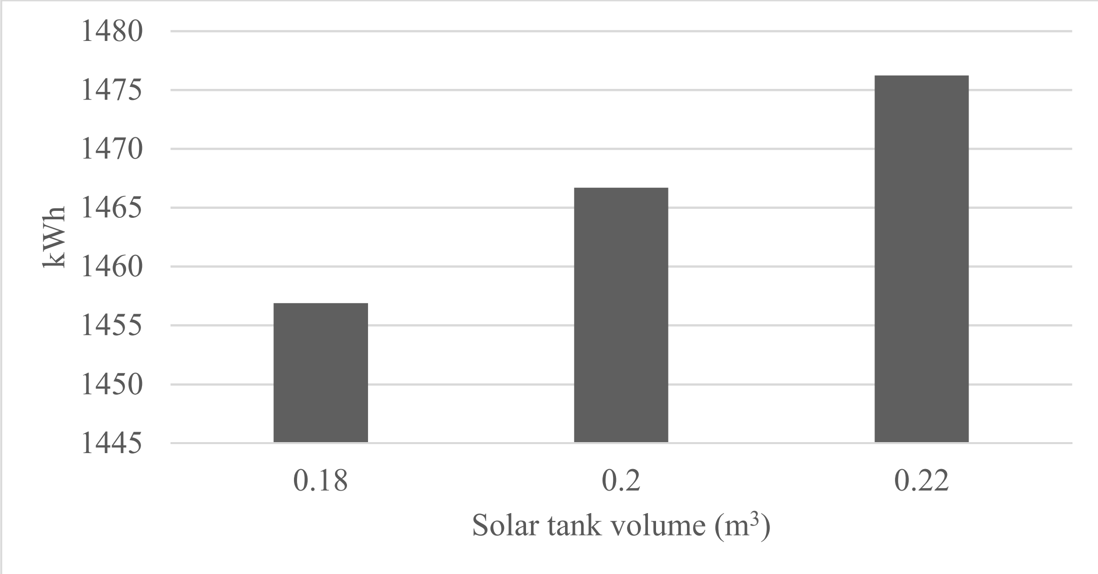

Figure 203: System energy for different solar tank volumes

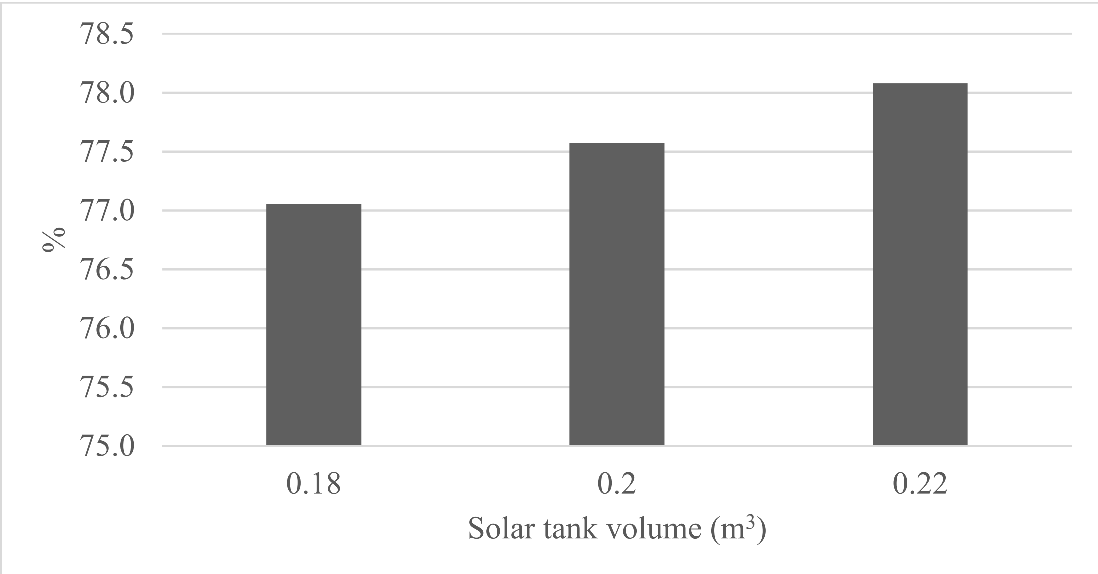

Figure 204: Solar fraction for different solar tank volumes

As shown in Figure 203, the energy produced by the system does not present large differences while the solar tank volume increases since the only thing that changes is the volume where water is stored. The highest value is in the case of 0,22 m^3. As presented in Figure 204, the increase in the solar tank volumes does not influence coverage as much, with the highest of 78% in 0,22 m^3, because the difference among them is 0,02 m^3 and the energy input of the domestic solar hot water system has small changes.

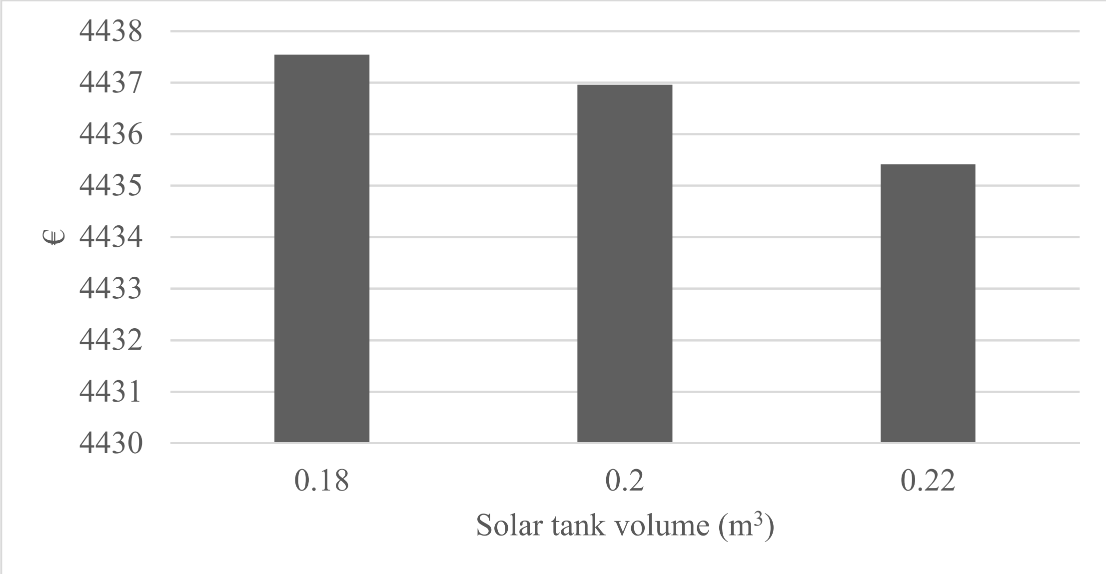

Figure 205: Net present value for different solar tank volumes

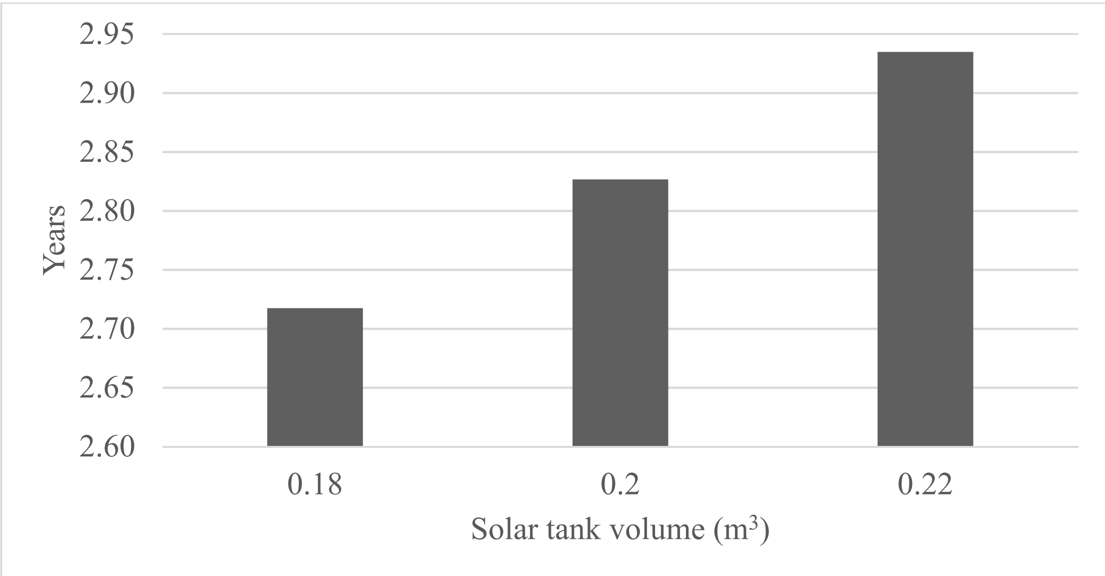

Figure 206: Payback period for different solar tank volumes

In Figure 205, the highest net present value is observed in 0,18 m^3 Thessaloniki with small dissimilarities and that is why in Figure 206, it has also the lowest payback period.

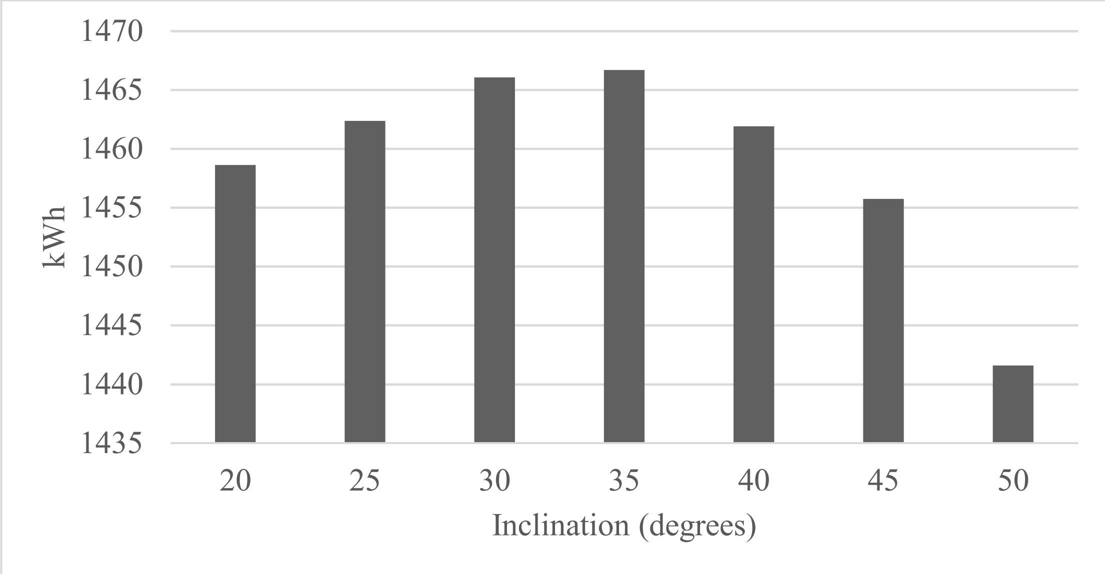

Figure 207: System energy for different inclinations

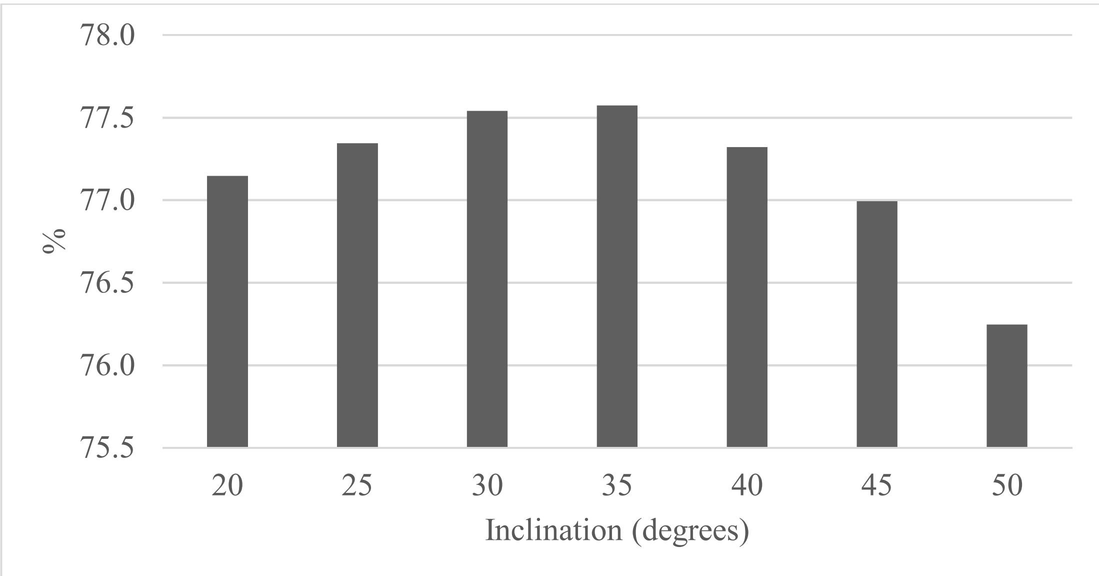

Figure 208: Solar fraction for different inclinations

In Figure 207, it is evident that the most energy is produced in the case of 35^{o} with 1.667 kWh while in Figure 208 the solar fraction is higher in 35^{o} with 77,6%. It is observed that after 35^{o} the solar fraction and the system energy are decreasing.

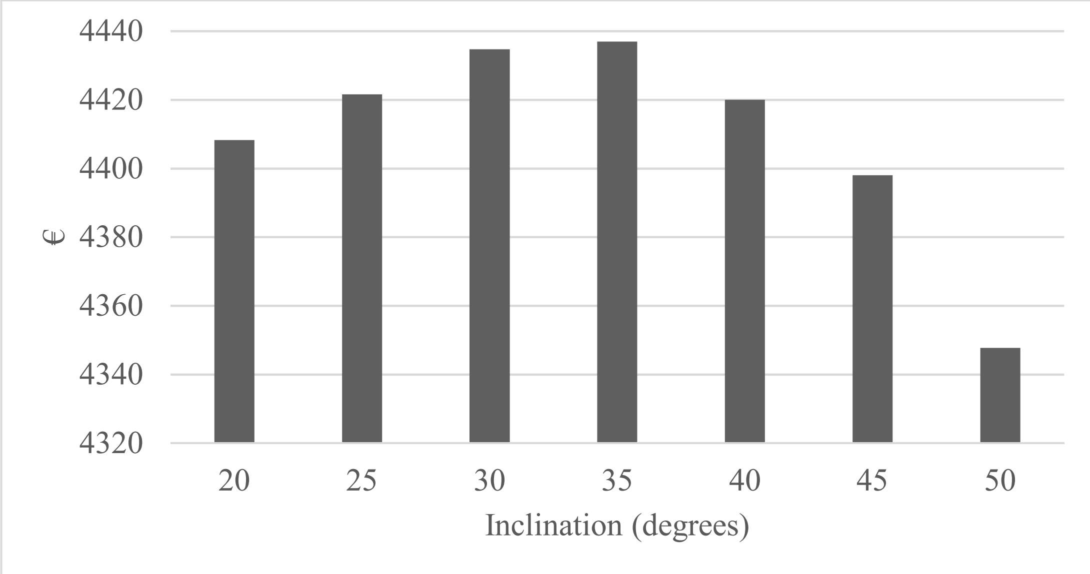

Figure 209: Net present value for different inclinations

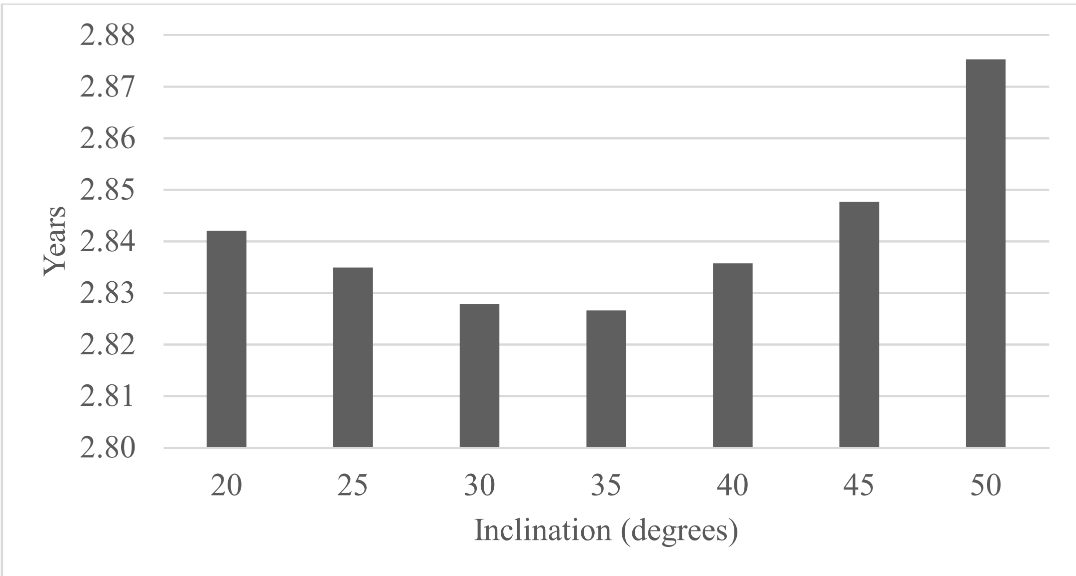

Figure 210: Payback period for different inclinations

In Figure 209, it is apparent that the highest net present value is noticed in 35º with 4.437€ making the project more economically feasible and in Figure 210, the lowest payback period is in the case of 35º with almost 2,8 years for the reason that where the economic benefit is higher the payback period will be shorter.

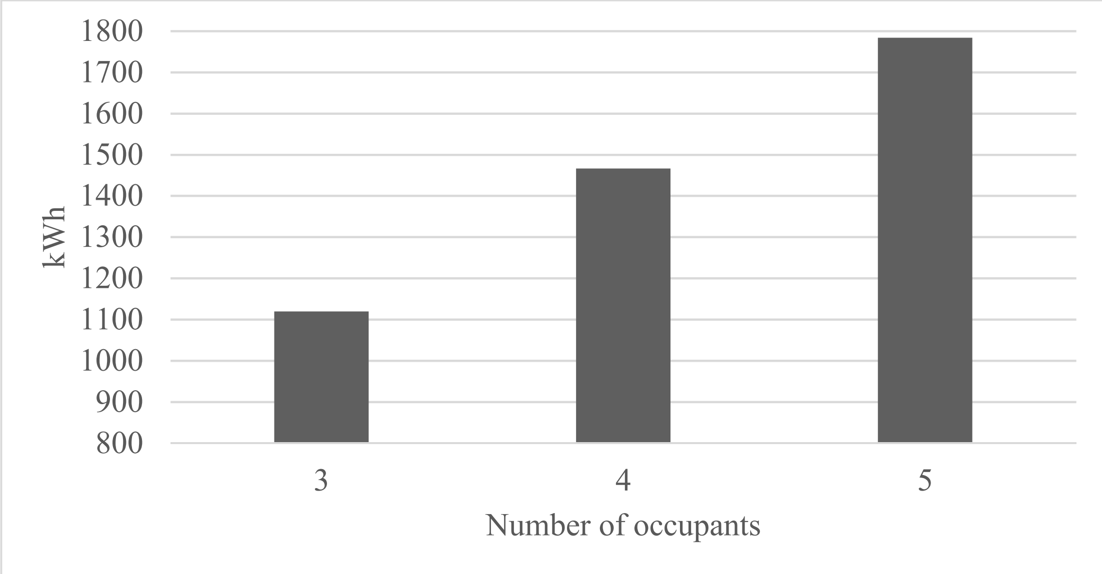

Figure 211: System energy for different occupants

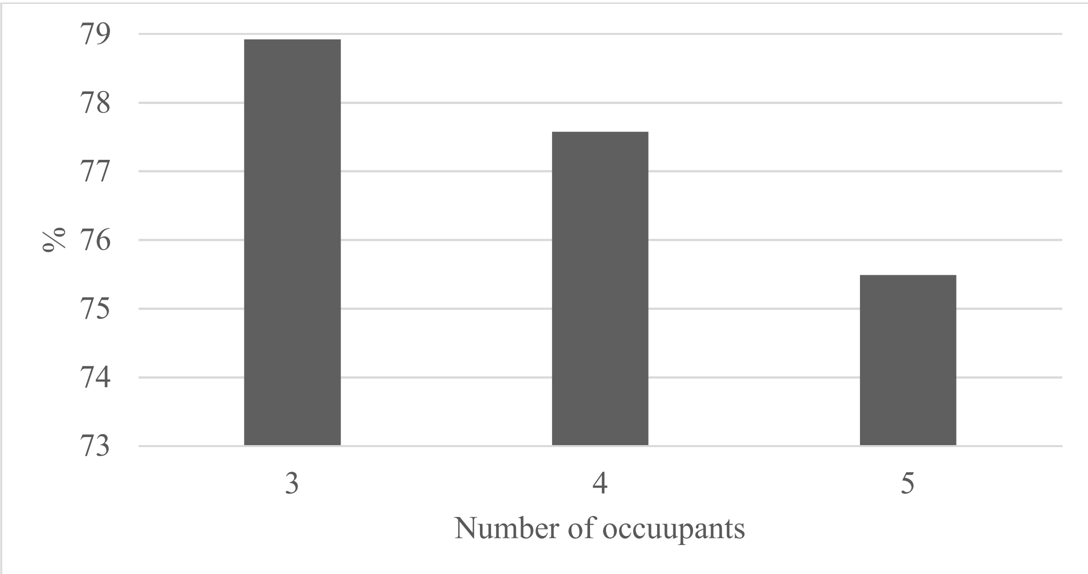

Figure 212: Solar fraction for different occupants

In Figure 211, it is evident that the most energy is produced for 5 occupants reaching 1.784 kWh as their average daily hot water usage is 250 kg/day and the system needs to produce more energy in order to cover their needs. Some solar gains that the domestic solar hot water system has during summer months may not be used and are lost. As the number of occupants increases, their energy demand also increases and these extra solar gains that were not previously used are in favor to cover the occupants' needs. In Figure 212, solar fraction presents a decrease as the number of occupants increases. The highest one is observed for 3 occupants being almost 79%

and their average hot water usage equals to 150 kg/day. Despite the fact that the energy produced by the system is increasing, the total energy required is higher and as a result the solar fraction is diminishing.

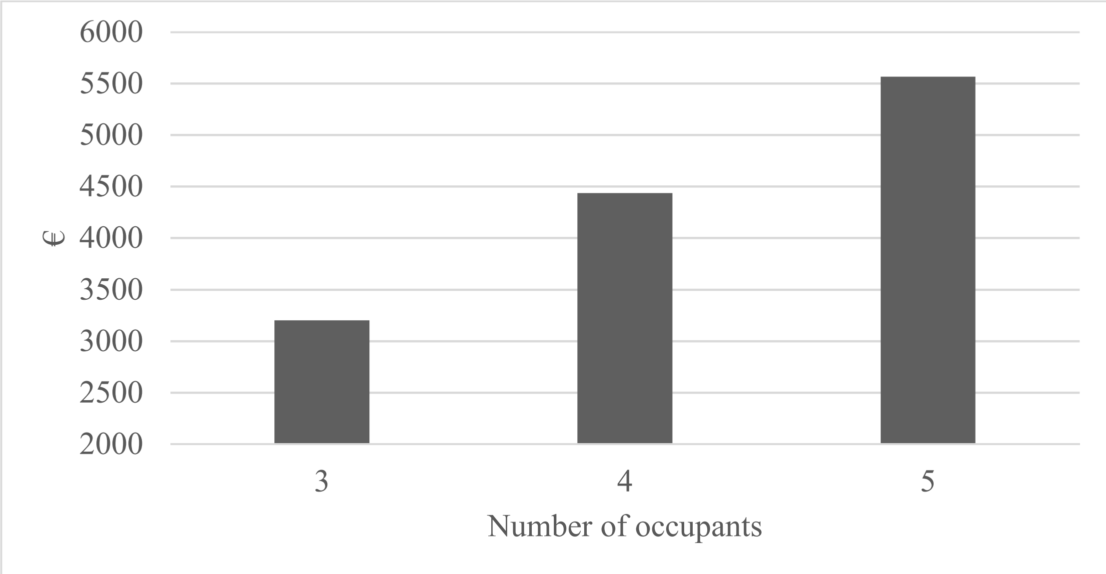

Figure 213: Net present value for different occupants

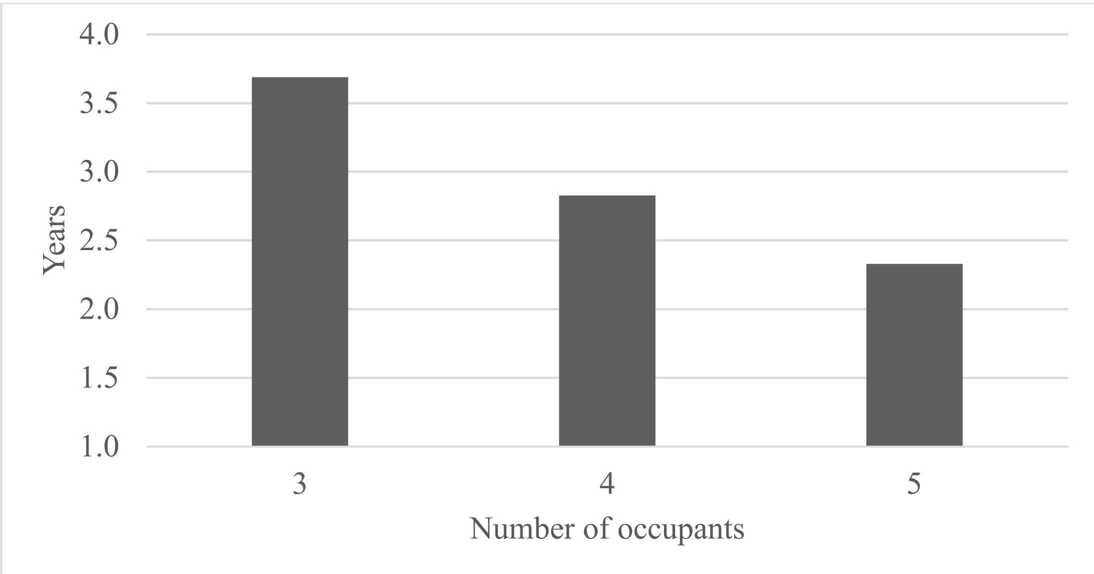

Figure 214: Payback period for different occupants

As shown in Figure 213, the highest net present value is observed at 5.566€ for 5 occupants making the project more economically feasible since the energy produced by the system in this case is the highest one. In Figure 214, the payback period is lowest for 5 occupants for 2,3 years which is in accordance to where there are large economic benefits, the payback period will be shorter.

It can be concluded that from Larnaca of Cyprus, the base case scenario (4 occupants, collector area= 4 m^2, $F_R(\tau\alpha)$= 0,76, F_RU_L= 4,5 W/m^2 C, inclination= 35^o) produces almost 1.467 kWh with solar fraction of 77,6%, the net present value is 4.437€ and the payback period reaches 2,8 years. In the first parametric analysis, the system produces more energy in the case of 3 collectors and has also the largest solar fraction and the highest net present value. In general, as the number of collectors increases, the solar fraction also increases but not with the same rate mainly because of the different energy demand during summer and winter months. Regarding payback period, the case of 1 collector has the highest one. Furthermore, the next parametric analysis showed that for system energy and solar fraction the case of 0,22 m^3 presents the highest values in 0,22 m^3 with small differences because the change in the solar tank volumes is 0,02 m^3 and the input of the produced energy by the domestic solar hot water system has minor dissimilarities.Net present value and payback period have better results in the case 0,18 m^3. Additionally, the parametric analysis having as input the inclination of the system showed that the best results were presented in 35^o regarding all aspects. Larnaca is located at North West Cyprus and has a hot semi-arid climate with hot or extremely hot summers and mild to warm winters. Finally, in the parametric analysis for the number of occupants, for system energy the highest value is noticed for 5 occupants as more energy is produced to cover their needs. As the number of occupants increases, the system takes advantage of the solar gains which in other cases (3 or 4 occupants) are lost and raises its energy production. It has the highest solar fraction for 3 occupants. Even if the domestic solar hot water system produces more energy for 5 occupants, the energy demand for them remains higher. It is reasonable since the less the number of people and their average daily hot water usage of 150 kg/day, the domestic solar hot water system can provide more coverage for their needs. Larnaca has the highest net present value and the shortest payback period following the essential of where the economic benefits are higher, the shorter is the payback period of the initial investment as electricity replacement.

Having calculated the solar fraction for a typical household types in Cyprus, a rough estimation of the total energy conservation that the use of solar thermal systems has in Cyprus is performed. According to the Statistical Service of Cyprus [71] the average size of a typical household consists of 3 occupants. The average solar fraction of the locations that corresponds to this number of occupants is 78,9% which means that the amount of energy saved annually from a domestic solar hot water system similar to the base case scenario results to 1.119 kWh per system. Taking into consideration the total glazed area of the country and the residential energy consumption [63], the total energy conservation for all systems in Cyprus during the last 10 years is estimated.

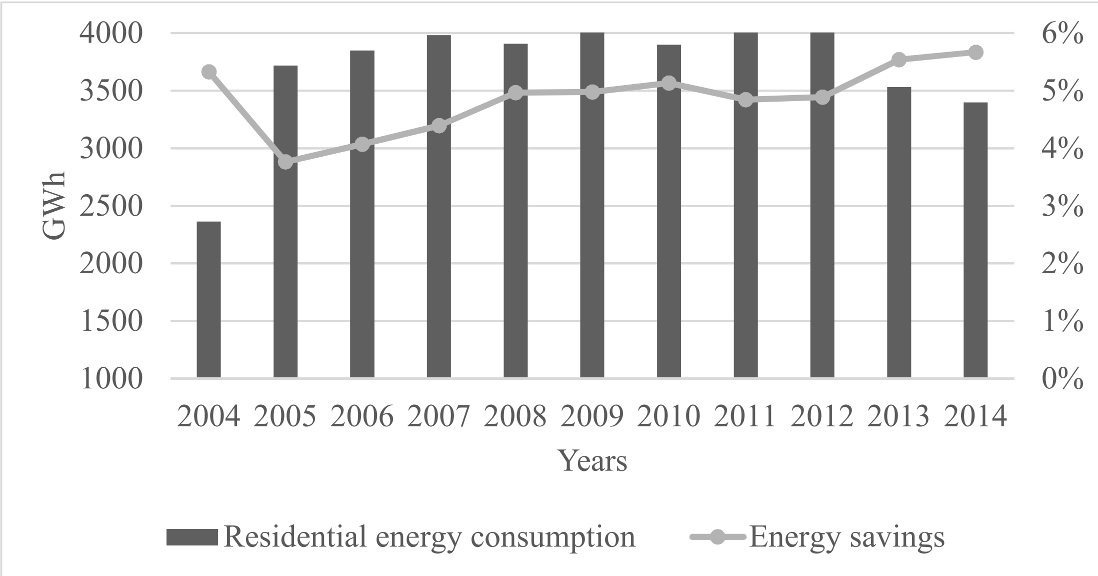

Figure 215: Total energy conservation

As presented in Figure 215, the total energy conservation increased slightly during the last years. It started with almost 126 GWh in 2004 and resulted to 192,5 GWh in 2014. There is an increase of almost 53% from 2004 to 2014. Since 2007, energy consumption in the residential sector has started to decrease except for some small increases. The reduction was influenced by economic performance, lower heat consumption due to better climatic conditions, more efficient electrical appliances and heating systems. In 2004, the potential energy savings deriving from the domestic solar hot water systems accounted for 5,3% of the total residential energy consumption. These savings reached to 5,7% of the total residential energy consumption in Cyprus in 2014.

In order to estimate the emissions reduction of GHG because of the domestic solar hot water systems usage, the emission factors for Cyprus per kWh of electricity generated were taken into consideration [64].

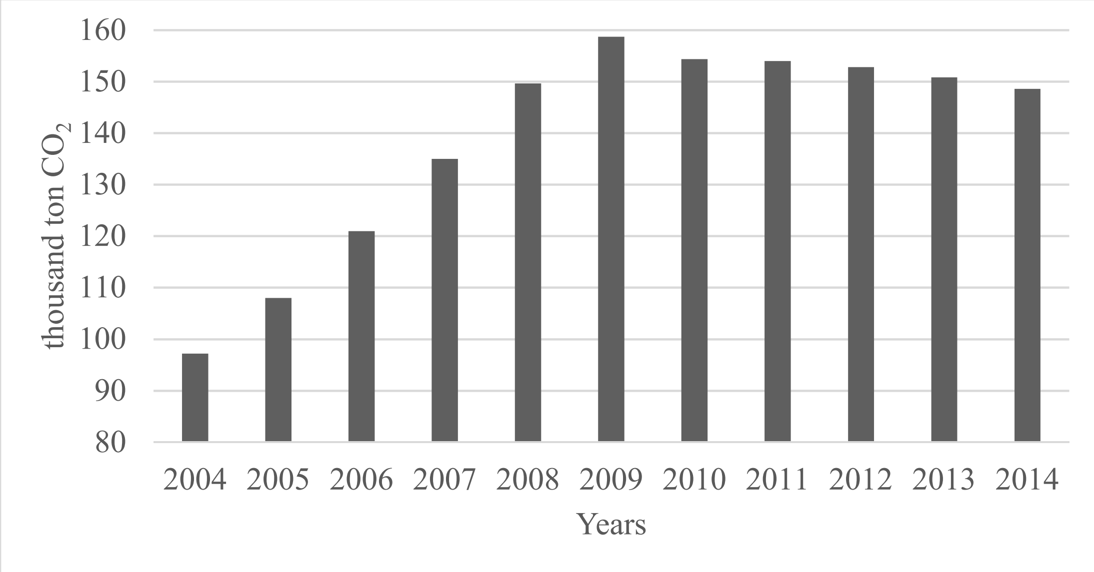

Figure 216: Tons of CO_2 saved

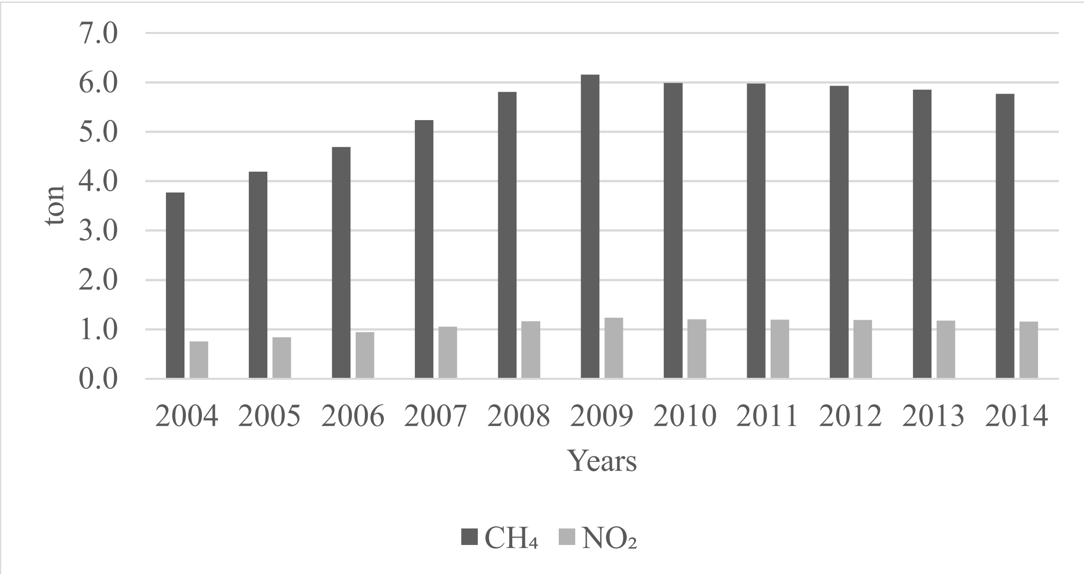

Figure 217: Tons of CH_4 and NO_2 saved

As presented in Figure 216, there was a steady increase of almost 53% for thousand tons of CO_2 saved by the domestic solar hot water systems usage from 2004 to 2014. It started with 97,2 thousand tons in 2004 and reached 148,6 thousand tons in 2014. The same happened with CH_4 and NO_2, as presented in Figure 217, that started with 3,8 and 0,75 tons in 2004 and reached 5,8 and 1,15 tons in 2014 respectively with their increase of saved tons being almost 53%.

5. CONCLUSIONS

In this dissertation, the solar coverage of domestic solar hot water systems was examined for typical residential buildings across EU. SAM was used in order to make the calculations, find the optimum angle for the collectors according to the countries' latitude and to estimate the energy savings and emissions reduction that can result from the domestic solar hot water systems usage for each country taken into account.

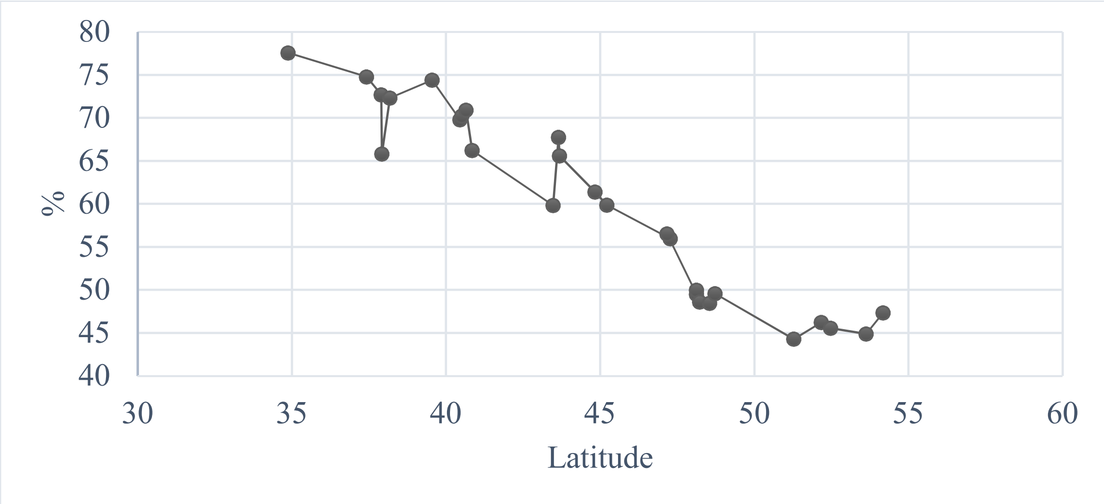

Figure 218: Solar fraction for EU locations

From Figure 218, it is evident that as the latitude increases, solar fraction is decreasing. Solar fraction ranges from 44,3% in Dusseldorf (51,28°) to 77,6% in Larnaca (34,88°) for EU locations that were examined. Regarding Central Europe, solar fraction ranges from 44% to 56% having a mix of temperate oceanic and continental climate with cold winters and hot summers. In Northern parts of Central Europe like Hamburg (53,63°) and Kolobrzeg (54.18°), average solar fraction is 46% while in central locations like Munich (48.13°) and Vienna (48.12°) reaches almost 50%. In Southern Europe, solar fraction ranges from 60% in Torino (45.22°) to 77,6% in Larnaca (34,88°) having warm and temperate Mediterranean climate with mild wet winters and hot and dry summers. In locations such as Sevilla (37,42°), Palermo (38,18°) and Andravida (37,92°), solar fraction reaches almost to 75%, 72,3% and 66% respectively. Finally, in Western Europe solar fraction ranges from 48,4% in Strasbourg (48,55°) to 67,7% in Nice (43,65°) having temperate and cool oceanic climate with warm winters and cool summers. It can be concluded that in Southern

Europe the domestic solar hot water system has higher solar fraction taking into consideration the energy demand of each country.

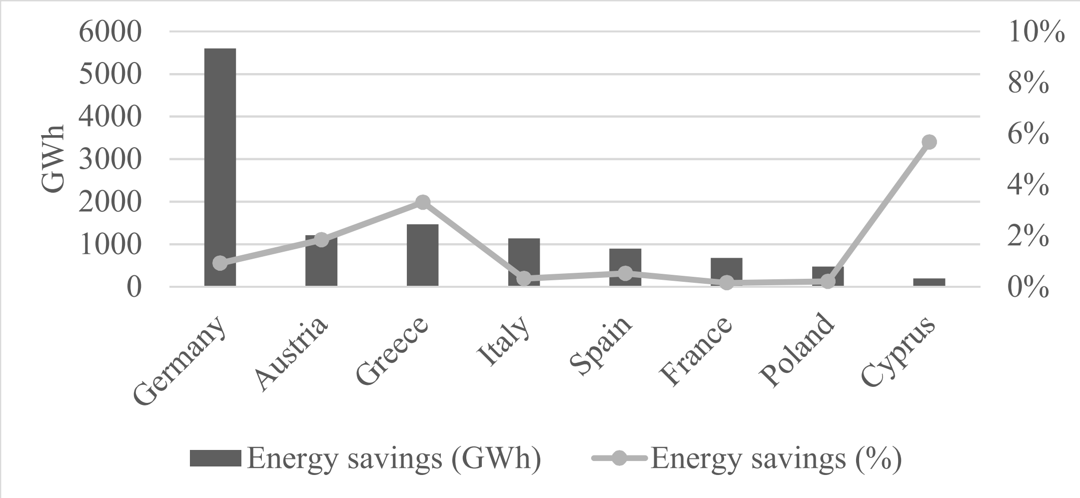

Figure 219: Energy savings in 2014

In Figure 219, it is apparent that despite Germany has saved the most with 5.600 GWh, these savings represent only 0,9% compared to its residential energy consumption. On the contrary, Greece and Cyprus that have saved much less, their savings represent 3,3% and 5,7% respectively compared to their residential energy consumption. In total, there is much to be done for EU countries in order to increase their energy savings compared to their residential energy consumption so as to reach the national goals set by each country.

An initial estimation was made for the quantity of CO_2 emissions that were saved in 2014 as shown in Figure 220.

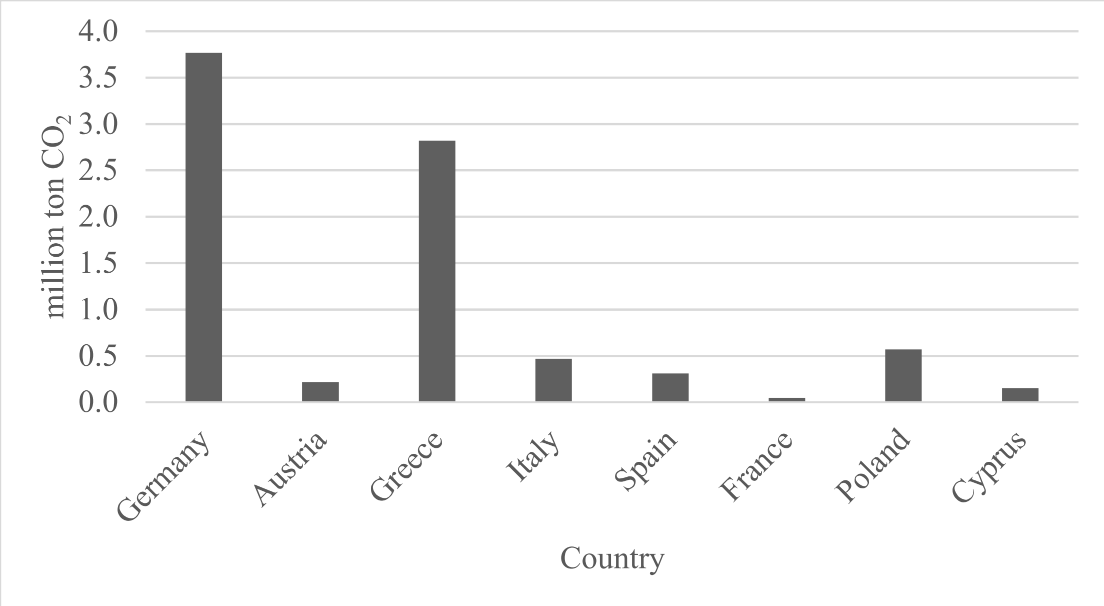

Figure 220: Tons of CO_2 saved in 2014

In Figure 220, it is evident that in Germany almost 3,8 million tons of CO_2 could be saved in 2014 with Greece ranking second with 2,8 million tons of CO_2. While France which is the sixth major market ranked last with 48 thousand tons of CO_2 and Cyprus which is the last solar thermal market, it could reach almost to 149 thousand tons of CO_2. Those calculations were made by taking into consideration the emission factors of produced electricity for each country along with the amount of energy produced by the domestic solar hot water systems and their installed collector area.

In conclusion, the total installed glazed area is continuously increasing and has almost tripled since 2003 in EU. Energy savings are also increasing compared to residential energy consumption but there is room for improvement. Finally, there is available potential for installing more domestic solar hot water systems since they are cost effective.

APPENDIX

GERMANY

Table 12: Parametric collectors

Location	Number of collectors	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Hamburg	1	30.36	840.95	4192.97	2.38
	2	44.88	1243.17	6309.39	2.09
	3	51.94	1438.74	7247.38	2.21
Berlin	1	31.50	850.70	4248.55	2.35
	2	45.54	1229.73	6232.75	2.11
	3	52.07	1406.12	7061.36	2.26
Dusseldorf	1	29.78	786.77	3883.99	2.54
	2	44.27	1169.51	5889.35	2.22
	3	51.01	1347.63	6727.87	2.36
Munich	1	35.40	1011.48	5001.05	2.04
	2	49.97	1427.53	7148.04	1.87
	3	56.30	1608.52	7954.56	2.04

Table 13: Parametric solar tank volumes

Location	Solar tank volume (m^3)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Hamburg	0.18	44.74	1239.30	6322.73	2.00
	0.2	44.88	1243.17	6309.39	2.09
	0.22	45.13	1250.25	6314.29	2.17
Berlin	0.18	45.31	1223.70	6233.80	2.03
	0.2	45.54	1229.73	6232.75	2.11
	0.22	45.73	1234.94	6227.01	2.20
Dusseldorf	0.18	44.02	1162.78	5886.40	2.13
	0.2	44.27	1169.51	5889.35	2.22
	0.22	44.42	1173.52	5876.77	2.31
Munich	0.18	49.62	1417.51	7136.00	1.80
	0.2	49.97	1427.53	7148.04	1.87
	0.22	50.24	1435.36	7147.61	1.94

Table 14: Parametric inclination

Location	Tilt (deg)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Hamburg	35	45.54	1261.37	6413.13	2.06
	40	45.50	1260.28	6406.93	2.06
	45	45.23	1253.02	6365.55	2.07
	50	44.88	1243.17	6309.39	2.09
	55	45.21	1252.38	6361.86	2.07
	60	44.68	1237.62	6277.71	2.10
	65	44.08	1220.96	6182.72	2.13
Berlin	35	45.58	1230.94	6239.65	2.11
	40	45.74	1235.34	6264.74	2.10
	45	45.74	1235.30	6264.51	2.10
	50	45.54	1229.73	6232.75	2.11
	55	45.98	1241.74	6301.20	2.09
	60	45.40	1226.12	6212.15	2.12
	65	44.53	1202.68	6078.46	2.16
Dusseldorf	35	45.30	1196.66	6044.14	2.17
	40	45.18	1193.47	6025.94	2.17
	45	44.88	1185.65	5981.38	2.19
	50	44.27	1169.51	5889.35	2.22
	55	44.53	1176.47	5929.02	2.20
	60	44.02	1162.87	5851.48	2.23
	65	43.33	1144.76	5748.18	2.26
Munich	35	50.36	1438.79	7212.23	1.85
	40	50.45	1441.37	7226.95	1.85
	45	50.39	1439.54	7216.52	1.85
	50	49.97	1427.53	7148.04	1.87
	55	50.20	1434.19	7186.01	1.86
	60	49.65	1418.35	7095.68	1.88
	65	48.81	1394.35	6958.82	1.91

Table 15: Parametric number of occupants

Location	Number of occupants	Average daily hot water usage (kg/day)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Hamburg	3	150	49.54	1029.12	5088.78	2.52
	4	200	44.88	1243.17	6309.39	2.09
	5	250	41.08	1422.39	7331.34	1.83
Berlin	3	150	49.94	1011.58	4988.73	2.56
	4	200	45.54	1229.73	6232.75	2.11
	5	250	41.62	1404.89	7231.55	1.85
Dusseldorf	3	150	48.56	962.08	4706.48	2.69
	4	200	44.27	1169.51	5889.35	2.22
	5	250	40.46	1336.17	6839.7	1.94
Munich	3	150	54.42	1165.97	5656.51	2.30
	4	200	49.97	1427.53	7148.04	1.87
	5	250	46.02	1643.37	8378.86	1.62

AUSTRIA

Table 16: Parametric collectors

Location	Number of collectors	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Linz	1	34.56	951.48	3039.17	3.12
	2	48.61	1338.25	4342.32	2.88
	3	55.23	1520.60	4863.03	3.11
Vienna	1	35.93	966.00	3094.77	3.08
	2	49.50	1330.86	4314.02	2.89
	3	55.68	1497.05	4772.88	3.15
Innsbruck	1	39.24	1086.74	3556.89	2.74
	2	55.95	1549.51	5150.89	2.49
	3	62.50	1730.97	5668.17	2.73

Table 17: Parametric solar tank volumes

Location	Solar tank volume (m^3)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Linz	0.18	48.36	1331.58	4352.20	2.76
	0.2	48.61	1338.25	4342.32	2.88
	0.22	48.80	1343.69	4327.70	3.00
Vienna	0.18	49.05	1318.84	4303.45	2.79
	0.2	49.50	1330.86	4314.02	2.89
	0.22	49.87	1340.89	4316.95	3.00
Innsbruck	0.18	55.50	1537.22	5139.27	2.40
	0.2	55.95	1549.51	5150.89	2.49
	0.22	56.28	1558.65	5150.43	2.59

Table 18: Parametric inclination

Location	Tilt (deg)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Linz	35	49.01	1349.33	4384.7	2.85
	40	49.06	1350.8	4390.36	2.85
	45	48.93	1347.21	4376.59	2.86
	50	48.61	1338.25	4342.32	2.88
	55	48.97	1348.4	4381.17	2.86
	60	48.21	1327.36	4300.62	2.90
	65	47.33	1303.2	4208.14	2.95
Vienna	35	49.69	1336.08	4333.98	2.88
	40	49.80	1339.02	4345.24	2.88
	45	49.74	1337.45	4339.23	2.88
	50	49.50	1330.86	4314.02	2.89
	55	49.79	1338.76	4344.24	2.88
	60	49.11	1320.38	4273.89	2.92
	65	48.35	1300.04	4196.06	2.96
Innsbruck	35	56.07	1553.02	5164.31	2.48
	40	56.35	1560.72	5193.78	2.47
	45	56.36	1561.04	5194.99	2.47
	50	55.95	1549.51	5150.89	2.49
	55	56.38	1561.58	5197.09	2.47
	60	55.92	1548.83	5148.29	2.49
	65	55.13	1526.98	5064.65	2.53

Table 19: Parametric number of occupants

Location	Number of occupants	Average daily hot water usage (kg/day)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Linz	3	150	53.16	1097.82	3422.10	3.50
	4	200	48.61	1338.25	4342.32	2.88
	5	250	44.70	1538.42	5108.41	2.51
Vienna	3	150	53.66	1081.94	3361.30	3.55
	4	200	49.50	1330.86	4314.02	2.89
	5	250	45.88	1541.93	5121.84	2.50
Innsbruck	3	150	60.53	1257.33	4032.58	3.06
	4	200	55.95	1549.51	5150.89	2.49
	5	250	51.76	1791.9	6078.57	2.16

GREECE

Table 20: Parametric collectors

Location	Number of collectors	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Thessaloniki	1	50.20	1330.85	3950.94	2.51
	2	70.25	1862.48	5592.68	2.32
	3	77.21	2047.07	6047.06	2.59
Athens	1	53.33	1300.83	3848.24	2.56
	2	72.69	1772.94	5286.35	2.43
	3	79.47	1938.27	5674.79	2.73
Andravida	1	45.55	1157.57	3358.08	2.88
	2	65.81	1672.35	4942.15	2.58
	3	74.04	1881.52	5480.64	2.81

Table 21: Parametric solar tank volumes

Location	Solar tank volume (m^3)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Thessaloniki	0.18	69.61	1845.57	5570.26	2.24
	0.2	70.25	1862.48	5592.68	2.32
	0.22	70.68	1873.93	5596.40	2.41
Athens	0.18	71.95	1754.88	5259.97	2.35
	0.2	72.69	1772.94	5286.35	2.43
	0.22	73.10	1782.90	5284.97	2.53
Andravida	0.18	65.52	1664.96	4952.34	2.47
	0.2	65.81	1672.35	4942.15	2.58
	0.22	66.00	1677.22	4923.37	2.69

Table 22: Parametric inclination

Location	Tilt (deg)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Thessaloniki	25	69.33	1838.19	5509.58	2.35
	30	70.03	1856.72	5572.97	2.33
	35	70.41	1866.90	5607.79	2.31
	40	70.40	1866.38	5606.03	2.31
	45	70.25	1862.48	5592.68	2.32
	50	69.83	1851.43	5554.88	2.33
	55	70.06	1857.40	5575.30	2.33
Athens	25	72.60	1770.71	5278.69	2.44
	30	73.01	1780.78	5313.14	2.42
	35	73.19	1785.08	5327.88	2.42
	40	73.11	1783.12	5321.15	2.42
	45	72.69	1772.94	5286.35	2.43
	50	72.07	1757.89	5234.84	2.46
	55	71.93	1754.36	5222.74	2.46
Andravida	25	66.50	1690.00	5002.54	2.55
	30	66.73	1695.92	5022.81	2.54
	35	66.60	1692.55	5011.27	2.55
	40	66.33	1685.65	4987.68	2.56
	45	65.81	1672.35	4942.15	2.58
	50	65.07	1653.58	4877.96	2.61
	55	65.07	1653.54	4877.79	2.61

Table 23: Parametric occupants

Location	Number of occupants	Average daily hot water usage (kg/day)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Thessaloniki	3	150	75.10	1493.33	4329.66	2.89
	4	200	70.25	1862.48	5592.68	2.32
	5	250	65.24	2161.97	6617.39	2.00
Athens	3	150	77.17	1411.68	4050.30	3.05
	4	200	72.69	1772.94	5286.35	2.43
	5	250	67.68	2063.39	6280.09	2.10
Andravida	3	150	70.83	1350.09	3839.58	3.19
	4	200	65.81	1672.35	4942.15	2.58
	5	250	60.67	1927.41	5814.85	2.24

ITALY

Table 24: Parametric collectors

Location	Number of collectors	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Torino	1	44.71	1118.03	4649.16	2.18
	2	59.85	1496.57	6250.03	2.11
	3	66.50	1662.74	6853.37	2.32
Pisa	1	51.06	1171.48	4900.24	2.08
	2	65.61	1505.22	6290.69	2.09
	3	71.53	1641.01	6751.30	2.35
Naples	1	50.81	1091.46	4524.37	2.23
	2	66.24	1422.97	5904.32	2.21
	3	72.36	1554.54	6345.16	2.48
Brindisi	1	56.42	1173.83	4911.28	2.07
	2	70.90	1475.07	6149.06	2.14
	3	76.10	1583.22	6479.88	2.44
Palermo	1	58.73	1137.87	4742.35	2.14
	2	72.32	1401.34	5802.75	2.25
	3	76.85	1488.98	6037.20	2.59

Table 25: Parametric solar tank volumes

Location	Solar tank volume (m^3)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Torino	0.18	59.55	1488.95	6249.72	2.02
	0.2	59.85	1496.57	6250.03	2.11
	0.22	60.18	1504.62	6252.41	2.19
Pisa	0.18	65.20	1495.72	6281.50	2.01
	0.2	65.61	1505.22	6290.69	2.09
	0.22	65.98	1513.74	6295.27	2.17
Naples	0.18	65.84	1414.46	5899.81	2.13
	0.2	66.24	1422.97	5904.32	2.21
	0.22	66.55	1429.66	5900.30	2.30
Brindisi	0.18	70.35	1463.71	6131.14	2.06
	0.2	70.90	1475.07	6149.06	2.14
	0.22	71.34	1484.32	6157.05	2.22
Palermo	0.18	71.69	1389.04	5780.39	2.16
	0.2	72.32	1401.34	5802.75	2.25
	0.22	72.85	1411.47	5814.86	2.33

Table 26: Parametric inclination

Location	Tilt (deg)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Torino	25	58.82	1470.75	6128.77	2.14
	30	59.59	1489.99	6219.15	2.11
	35	59.99	1499.92	6265.78	2.10
	40	59.85	1496.57	6250.03	2.11
	45	59.68	1492.19	6229.48	2.11
	50	59.55	1488.94	6214.21	2.12
	55	60.10	1502.69	6278.80	2.10
Pisa	25	64.62	1482.56	6184.24	2.12
	30	65.15	1494.59	6240.75	2.11
	35	65.39	1500.23	6267.26	2.10
	40	65.61	1505.22	6290.69	2.09
	45	65.35	1499.15	6262.17	2.10
	50	65.02	1491.64	6226.90	2.11
	55	65.24	1496.81	6251.19	2.10
Naples	25	65.78	1413.19	5858.38	2.23
	30	66.19	1421.90	5899.29	2.21
	35	66.28	1423.93	5908.84	2.21
	40	66.24	1422.97	5904.32	2.21
	45	66.00	1417.79	5880.01	2.22
	50	65.38	1404.57	5817.90	2.24
	55	65.42	1405.50	5822.28	2.24
Brindisi	25	69.87	1453.73	6048.82	2.17
	30	70.44	1465.57	6104.41	2.15
	35	70.76	1472.21	6135.64	2.14
	40	70.90	1475.07	6149.06	2.14
	45	70.81	1473.32	6140.83	2.14
	50	70.35	1463.72	6095.73	2.15
	55	70.23	1461.10	6083.45	2.16

Palermo	25	72.23	1399.51	5794.14	2.25
	30	72.56	1405.91	5824.18	2.24
	35	72.53	1405.42	5821.89	2.24
	40	72.32	1401.34	5802.75	2.25
	45	71.82	1391.59	5756.95	2.26
	50	71.29	1381.29	5708.57	2.28
	55	71.24	1380.41	5704.43	2.28

Table 27: Parametric occupants

Location	Number of occupants	Average daily hot water usage (kg/day)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Paybac k period (years)
Torino	3	150	64.04	1200.91	4861.26	2.62
	4	200	59.85	1496.57	6250.03	2.11
	5	250	55.97	1749.34	7437.36	1.80
Pisa	3	150	69.13	1189.44	4807.38	2.64
	4	200	65.61	1505.22	6290.69	2.09
	5	250	62.17	1782.75	7594.31	1.77
Naples	3	150	69.41	1118.39	4473.66	2.81
	4	200	66.24	1422.97	5904.32	2.21
	5	250	62.76	1685.32	7136.67	1.87
Brindisi	3	150	73.56	1147.80	4611.81	2.74
	4	200	70.90	1475.07	6149.06	2.14
	5	250	67.70	1760.68	7490.64	1.79
Palermo	3	150	74.59	1083.92	4311.77	2.90
	4	200	72.32	1401.34	5802.75	2.25
	5	250	69.49	1682.96	7125.55	1.87

SPAIN

Table 28: Parametric collectors

Location	Number of collectors	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Santander	1	44.09	1003.64	3995.43	2.48
	2	59.81	1361.63	5458.30	2.37
	3	65.70	1495.61	5894.88	2.64
Madrid	1	56.33	1305.33	5377.57	1.91
	2	69.80	1617.55	6630.71	2.00
	3	74.54	1727.43	6956.90	2.29
Palma	1	60.79	1286.95	5293.34	1.94
	2	74.40	1574.88	6435.26	2.05
	3	78.39	1659.52	6645.78	2.38
Sevilla	1	64.41	1270.47	5217.84	1.97
	2	74.76	1474.61	5975.89	2.19
	3	78.29	1544.29	6117.89	2.56

Table 29: Parametric solar tank volumes

Location	Solar tank volume (m^3)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Santander	0.18	59.25	1348.77	5434.84	2.28
	0.2	59.81	1361.63	5458.30	2.37
	0.22	60.27	1371.94	5470.10	2.46
Madrid	0.18	69.22	1604.24	6605.18	1.92
	0.2	69.80	1617.55	6630.71	2.00
	0.22	70.27	1628.37	6644.84	2.07
Palma	0.18	73.73	1560.77	6406.05	1.98
	0.2	74.40	1574.88	6435.26	2.05
	0.22	74.97	1587.03	6455.47	2.13
Sevilla	0.18	73.99	1459.47	5941.95	2.11
	0.2	74.76	1474.61	5975.89	2.19
	0.22	75.45	1488.28	6003.04	2.27

Table 30: Parametric inclination

Location	Tilt (deg)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Santander	25	59.54	1355.30	5429.29	2.38
	30	59.85	1362.56	5462.53	2.37
	35	59.94	1364.56	5471.70	2.36
	40	59.81	1361.63	5458.30	2.37
	45	59.42	1352.72	5417.45	2.38
	50	58.77	1337.77	5349.00	2.41
	55	59.01	1343.23	5373.97	2.40
Madrid	25	69.40	1608.21	6587.92	2.01
	30	69.64	1613.82	6613.65	2.00
	35	69.81	1617.75	6631.61	2.00
	40	69.80	1617.55	6630.71	2.00
	45	69.24	1604.72	6571.92	2.01
	50	68.80	1594.41	6524.71	2.03
	55	68.82	1594.89	6526.89	2.03
Palma	25	73.69	1559.89	6366.56	2.07
	30	73.99	1566.29	6395.86	2.06
	35	74.30	1572.92	6426.26	2.05
	40	74.40	1574.88	6435.26	2.05
	45	74.23	1571.45	6419.52	2.06
	50	73.88	1564.01	6385.41	2.07
	55	73.60	1558.03	6358.03	2.07
Sevilla	25	75.08	1481.09	6005.57	2.18
	30	75.20	1483.32	6015.76	2.18
	35	74.99	1479.20	5996.92	2.18
	40	74.76	1474.61	5975.89	2.19
	45	74.36	1466.91	5940.58	2.20
	50	74.11	1461.89	5917.62	2.21
	55	74.13	1462.25	5919.26	2.21

Table 31: Parametric occupants

Location	Number of occupants	Average daily hot water usage (kg/day)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Santander	3	150	63.47	1083.60	4184.55	2.97
	4	200	59.81	1361.63	5458.30	2.37
	5	250	56.20	1599.07	6546.06	2.02
Madrid	3	150	72.53	1260.71	4995.96	2.56
	4	200	69.80	1617.55	6630.71	2.00
	5	250	66.53	1927.27	8049.63	1.68
Palma	3	150	76.78	1219.01	4804.9	2.64
	4	200	74.40	1574.88	6435.26	2.05
	5	250	71.45	1890.78	7882.46	1.71
Sevilla	3	150	76.47	1131.34	4403.29	2.84
	4	200	74.76	1474.61	5975.89	2.19
	5	250	72.39	1784.92	7397.49	1.81

FRANCE

Table 32: Parametric collectors

Location	Number of collectors	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Paris	1	34.59	895.13	2304.40	3.90
	2	49.58	1283.31	3387.83	3.53
	3	56.46	1461.35	3788.80	3.80
Strasbourg	1	34.75	924.41	2399.51	3.78
	2	48.44	1288.57	3404.90	3.51
	3	54.98	1462.41	3792.24	3.79
Nantes	1	40.78	1017.62	2702.23	3.44
	2	56.53	1410.47	3800.76	3.21
	3	63.19	1576.67	4163.30	3.52
Bordeaux	1	44.16	1065.23	2856.81	3.29
	2	61.39	1480.78	4029.10	3.06
	3	68.09	1642.40	4376.75	3.38
Nice	1	53.77	1191.92	3268.23	2.94
	2	67.74	1501.53	4096.49	3.02
	3	72.63	1610.08	4271.80	3.45

Table 33: Parametric solar tank volumes

Location	Solar tank volume (m^3)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Paris	0.18	49.29	1275.82	3398.95	3.39
	0.2	49.58	1283.31	3387.83	3.53
	0.22	49.83	1289.67	3373.04	3.67
Strasbourg	0.18	48.21	1282.49	3420.59	3.37
	0.2	48.44	1288.57	3404.90	3.51
	0.22	48.70	1295.33	3391.44	3.65
Nantes	0.18	56.12	1400.40	3803.52	3.09
	0.2	56.53	1410.47	3800.76	3.21
	0.22	56.84	1418.15	3790.28	3.34
Bordeaux	0.18	60.98	1470.87	4032.36	2.95
	0.2	61.39	1480.78	4029.10	3.06
	0.22	61.66	1487.38	4015.11	3.19
Nice	0.18	67.09	1487.23	4085.49	2.91
	0.2	67.74	1501.53	4096.49	3.02
	0.22	68.33	1514.64	4103.64	3.13

Table 34: Parametric inclination

Location	Tilt (deg)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Paris	30	49.52	1281.72	3382.67	3.53
	35	49.73	1287.15	3400.29	3.52
	40	49.74	1287.34	3400.92	3.51
	45	49.58	1283.31	3387.83	3.53
	50	49.21	1273.61	3356.33	3.55
	55	49.41	1278.81	3373.23	3.54
	60	48.68	1260.00	3312.12	3.59
Strasbourg	30	48.87	1299.99	3442.00	3.48
	35	49.06	1305.04	3458.40	3.47
	40	48.93	1301.47	3446.82	3.48
	45	48.44	1288.57	3404.90	3.51
	50	47.82	1271.93	3350.89	3.56
	55	48.19	1281.95	3383.40	3.53
	60	47.71	1269.09	3341.65	3.56
Nantes	30	56.11	1400.10	3767.09	3.24
	35	56.46	1408.68	3794.97	3.22
	40	56.58	1411.89	3805.39	3.21
	45	56.53	1410.47	3800.76	3.21
	50	56.27	1404.07	3780.00	3.23
	55	56.54	1410.89	3802.15	3.21
	60	55.77	1391.54	3739.29	3.26
Bordeaux	30	60.84	1467.52	3986.04	3.09
	35	61.23	1477.08	4017.08	3.07
	40	61.43	1481.90	4032.74	3.06
	45	61.39	1480.78	4029.10	3.06
	50	61.15	1475.01	4010.38	3.07
	55	61.35	1479.80	4025.93	3.07
	60	60.62	1462.23	3968.88	3.10

Nice	30	68.13	1510.31	4125.00	3.00
	35	68.30	1514.02	4137.06	3.00
	40	68.05	1508.58	4119.39	3.01
	45	67.74	1501.53	4096.49	3.02
	50	67.51	1496.45	4080.00	3.03
	55	67.77	1502.25	4098.84	3.02
	60	67.45	1495.22	4076.01	3.03

Table 35: Parametric occupants

Location	Number of occupants	Average daily hot water usage (kg/day)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Paris	3	150	54.03	1048.87	2626.49	4.30
	4	200	49.58	1283.31	3387.83	3.53
	5	250	45.59	1474.81	4009.71	3.08
Strasbourg	3	150	52.63	1049.94	2629.98	4.29
	4	200	48.44	1288.57	3404.90	3.51
	5	250	44.84	1491.12	4062.68	3.04
Nantes	3	150	60.89	1139.42	2920.54	3.96
	4	200	56.53	1410.47	3800.76	3.21
	5	250	52.58	1640.06	4546.36	2.77
Bordeaux	3	150	65.69	1188.40	3079.62	3.80
	4	200	61.39	1480.78	4029.10	3.06
	5	250	57.10	1721.62	4811.23	2.64
Nice	3	150	71.00	1180.41	3053.67	3.83
	4	200	67.74	1501.53	4096.49	3.02
	5	250	64.46	1786.14	5020.74	2.55

POLAND

Table 36: Parametric collectors

Location	Number of collectors	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Kolobrzeg	1	32.83	924.02	1933.84	4.46
	2	47.33	1332.13	2876.85	4.01
	3	53.70	1511.59	3192.25	4.33
Warsaw	1	31.59	891.83	1845.49	4.61
	2	46.22	1304.77	2801.77	4.09
	3	53.00	1496.27	3150.21	4.37

Table 37: Parametric solar tank volumes

Location	Solar tank volume (m^3)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Kolobrzeg	0.18	47.14	1326.90	2897.95	3.85
	0.2	47.33	1332.13	2876.85	4.01
	0.22	47.52	1337.46	2856.06	4.17
Warsaw	0.18	46.00	1298.56	2820.16	3.93
	0.2	46.22	1304.77	2801.77	4.09
	0.22	46.45	1311.26	2784.12	4.25

Table 38: Parametric inclination

Location	Tilt (deg)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Kolobrzeg	35	47.56	1338.78	2895.10	3.99
	40	47.65	1341.35	2902.16	3.98
	45	47.60	1339.85	2898.06	3.99
	50	47.33	1332.13	2876.85	4.01
	55	47.79	1345.07	2912.39	3.97
	60	47.36	1333.02	2879.31	4.01
	65	46.36	1304.96	2802.29	4.09
Warsaw	35	46.76	1320.02	2843.63	4.05
	40	46.80	1321.20	2846.86	4.04
	45	46.60	1315.53	2831.29	4.06
	50	46.22	1304.77	2801.77	4.09
	55	46.56	1314.38	2828.15	4.06
	60	45.97	1297.93	2783.00	4.11
	65	45.36	1280.54	2735.27	4.17

Table 39: Parametric occupants

Location	Number of occupants	Average daily hot water usage (kg/day)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Kolobrzeg	3	150	51.50	1087.20	2204.55	4.89
	4	200	47.33	1332.13	2876.85	4.01
	5	250	43.74	1539.08	3444.91	3.48
Warsaw	3	150	51.11	1082.22	2190.88	4.91
	4	200	46.22	1304.77	2801.77	4.09
	5	250	42.23	1490.35	3311.17	3.59

CYPRUS

Table 40: Parametric collectors

Location	Number of collectors	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Larnaca	1	66.24	1252.47	3852.23	2.56
	2	77.57	1466.68	4436.96	2.83
	3	81.57	1542.22	4528.41	3.29

Table 41: Parametric solar tank volumes

Location	Solar tank volume (m^3)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Larnaca	0.18	77.06	1456.89	4437.54	2.72
	0.2	77.57	1466.68	4436.96	2.83
	0.22	78.08	1476.22	4435.41	2.93

Table 42: Parametric inclination

Location	Tilt (deg)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Larnaca	20	77.15	1458.62	4408.28	2.84
	25	77.34	1462.36	4421.56	2.83
	30	77.54	1466.06	4434.72	2.83
	35	77.57	1466.68	4436.96	2.83
	40	77.32	1461.91	4419.98	2.84
	45	76.99	1455.73	4397.98	2.85
	50	76.25	1441.59	4347.70	2.88

Table 43: Parametric occupants

Location	Number of occupants	Average daily hot water usage (kg/day)	Solar fraction (%)	System energy (kWh)	Net present value (€)	Payback period (years)
Larnaca	3	150	78.92	1119.09	3200.66	3.69
	4	200	77.57	1466.68	4436.96	2.83
	5	250	75.49	1784.10	5565.93	2.33

REFERENCES

[1] US Energy Information Administration, Annual Energy Outlook (2014)

[2] European Commission, https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings

[3] Eurostat, http://ec.europa.eu/eurostat/web/energy/data/main-tables

[4] European Environment Agency, "Final energy consumption by sector and fuel.", http://www.eea.europa.eu/data-and-maps/indicators/final-energy-consumption-by-sector-9/assessment

[5] Lapillonne, Bruno, Karine Pollier, and Nehir Samci. "Energy efficiency trends for households in the EU." Enerdata. Retrieved June 22 (2014): 2015.

[6] European Environment Agency, "Energy efficiency and energy consumption in the household sector.", http://www.eea.europa.eu/data-and-maps/indicators/energy-efficiency-and-energy-consumption-5/assessment

[7] Gynther, L., B. Lapillone, and K. Pollier. "Energy Efficiency Trends and Policies in the Household and Tertiary Sectors." An Analysis Based on the ODYSSEE and MURE Databases (2015).

[8] Kanellakis, Marinos, Georgios Martinopoulos, and Theodoros Zachariadis. "European energy policy—A review." Energy Policy 62 (2013): 1020-1030.

[9] European Commission, https://ec.europa.eu/energy/en/topics/renewable-energy

[10] European Commission "Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)."Official Journal of the European Union, L153 of 18.6.2010, p.13-35

[11] European Commission. "Directive 2012/27/EU of the European Parliament and of the council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. "Official Journal of the European Union, L 315 of 14.11.2012, p.1-56

[12] European Commission "Directive 2006/32/EC of the European Parliament and of the Council of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC "Official Journal of the European Union, L 114 of 27.4.2006, p. 64–85

[13] European Commission "Directive 2004/8/EC of the European Parliament and of the Council of 11 February 2004 on the promotion of cogeneration based on a useful heat demand in the internal energy market and amending Directive 92/42/EEC "Official Journal of the European Union, L 52 of 21.2.2004, p. 50–60

[14] European Commission "Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC "Official Journal of the European Union, L 140 of 5.6.2009, p. 16–62

[15] Marszal, Anna Joanna, et al. "Zero Energy Building–A review of definitions and calculation methodologies." Energy and buildings 43.4 (2011): 971-979.

[16] Economidou, Marina, et al. "Europe's buildings under the microscope. A country-by-country review of the energy performance of buildings." Buildings Performance Institute Europe (BPIE) (2011)

[17] Seddegh, Saeid, et al. "Solar domestic hot water systems using latent heat energy storage medium: A review." Renewable and Sustainable energy reviews 49 (2015): 517-533.

[18] Eichhammer, Wolfgang, et al. "Study on the energy savings potentials in EU member states, candidate countries and EEA countries: final report." (2011).

[19] Wesselink, Bart, and I. Deng. "Sectoral emission reduction potentials and economic costs for climate change." London: ECOFYS (2009).

[20] Boermans, T., and J. Grözinger. "Economic effects of investing in EE in buildings–the BEAM2 Model." Background paper for EC Workshop on Cohesion policy. 2011.

[21] European Solar Thermal Industry Federation, (ESTIF) http://www.estif.org/fileadmin/estif/content/market_data/downloads/Solar_Thermal_Markets_in_Europe_2003.pdf

[22] European Solar Thermal Industry Federation, (ESTIF), http://www.estif.org/fileadmin/estif/content/market_data/downloads/Solar_Thermal_Markets_in_Europe_2004.pdf

[23] European Solar Thermal Industry Federation, (ESTIF), http://www.estif.org/fileadmin/estif/content/market_data/downloads/Solar_Thermal_Markets_in_Europe_2005.pdf

[24] European Solar Thermal Industry Federation, (ESTIF), http://www.estif.org/fileadmin/estif/content/market_data/downloads/Solar_Thermal_Markets_in_Europe_2006.pdf

[25] European Solar Thermal Industry Federation, (ESTIF), http://www.estif.org/fileadmin/estif/content/market_data/downloads/2009%20solar_thermal_markets.pdf

[26] European Solar Thermal Industry Federation, (ESTIF), http://www.estif.org/fileadmin/estif/content/market_data/downloads/2010%20European%20Solar%20Thermal%20Markets.pdf

[27] European Solar Thermal Industry Federation, (ESTIF), http://www.estif.org/fileadmin/estif/content/market_data/downloads/Solar%20Thermal%20Markets%20in%20Europe%20-%20Trends%20and%20Market%20Stat.pdf

[28] European Solar Thermal Industry Federation, (ESTIF), http://www.estif.org/fileadmin/estif/content/market_data/downloads/Solar_Thermal_M%20arkets%202012.pdf

[29] European Solar Thermal Industry Federation, (ESTIF), http://www.estif.org/fileadmin/estif/content/market_data/downloads/solar_thermal_markets2013_v01.pdf

[30] European Solar Thermal Industry Federation, (ESTIF), http://www.estif.org/fileadmin/estif/content/market_data/downloads/2014_solar_thermal_markets_LR.pdf

[31] Ibrahim, Oussama, et al. "Review of water-heating systems: General selection approach based on energy and environmental aspects." Building and Environment 72 (2014): 259-286.

[32] DeWinter, Francis. Solar collectors, energy storage, and materials. Vol. 5. MIT press, 1990.

[33] Kalogirou, Soteris. "Thermal performance, economic and environmental life cycle analysis of thermosiphon solar water heaters." Solar energy 83.1 (2009): 39-48.

[34] Tsilingiridis, G., and G. Martinopoulos. "Thirty years of domestic solar hot water systems use in Greece–energy and environmental benefits–future perspectives." Renewable Energy 35.2 (2010): 490-497.

[35] ECOFYS. Soltherm Europe – European market report. European Commission DG TREN; 2003.

[36] Benli, Hüseyin. "Potential application of solar water heaters for hot water production in Turkey." Renewable and Sustainable Energy Reviews 54 (2016): 99-109.

[37] Shah, Louise Jivan, and Simon Furbo. "Vertical evacuated tubular-collectors utilizing solar radiation from all directions." Applied Energy 78.4 (2004): 371-395.

[38] Mills, David. "Assessing solar hot water system performance with GIS." Solar energy 76.1 (2004): 153-157.

[39] Rogers, J. G., M. C. McManus, and S. J. G. Cooper. "Potential for reliance on solar water heating throughout the summer in northern cloudy climates." Energy and Buildings 66 (2013): 128-135.

[40] Tsalikis, Georgios, and Georgios Martinopoulos. "Solar energy systems potential for nearly net zero energy residential buildings." Solar Energy 115 (2015): 743-756.

[41] Shariah, Adnan, M-Ali Al-Akhras, and I. A. Al-Omari. "Optimizing the tilt angle of solar collectors." Renewable Energy 26.4 (2002): 587-598.

[42] Kalogirou, Soteris A. "Environmental benefits of domestic solar energy systems." Energy conversion and management 45.18 (2004): 3075-3092.

[43] Abd-ur-Rehman, Hafiz M., and Fahad A. Al-Sulaiman. "Optimum selection of solar water heating (SWH) systems based on their comparative techno-economic feasibility study for the domestic sector of Saudi Arabia." Renewable and Sustainable Energy Reviews 62 (2016): 336-349.

[44] Duomarco, José Luis. "Figure of merit for solar domestic hot water systems." Solar Energy 111 (2015): 151-156.

[45] Park, Youn Cheol. "A study on automatic optimal operation of a pump for solar domestic hot water system." Solar Energy 98 (2013): 448-457.

[46] Blair, Nate, et al. "System advisor model, sam 2014.1. 14: General description." Nat. Renew. Energy Lab., Denver, CO, USA, Tech. Rep. NREL/TP-6A20-61019 (2014).

[47] Freeman, Janine, et al. "Validation of multiple tools for flat plate photovoltaic modeling against measured data." 2014 IEEE 40th Photovoltaic Specialist Conference (PVSC). IEEE, 2014.

[48] Rudié, E., Thornton, A., Rajendra, N., Kerrigan, S. (2014). System Advisor Model Performance Modeling Validation Report: Analysis of 100 Sites. Locus Energy

[49] Freeman, Janine, et al. "System advisor model: Flat plate photovoltaic performance modeling validation report." National Renewable Energy Lab., Golden, CO (US) (2013).

[50] Blair, N., A. Dobos, and N. Sather. "Case studies comparing System Advisor Model (SAM) results to real performance data." Conference proceedings of ASES/WREF. 2012.

[51] Collado, Francisco J., and Jesus Guallar. "Two-stages optimised design of the collector field of solar power tower plants." Solar Energy 135 (2016): 884-896.

[52] Jones-Albertus, Rebecca, et al. "Technology advances needed for photovoltaics to achieve widespread grid price parity." Progress in Photovoltaics: Research and Applications (2016).

[53] Martinopoulos, Georgios, and Georgios Tsalikis. "Active solar heating systems for energy efficient buildings in Greece: A technical economic and environmental evaluation." Energy and Buildings 68 (2014): 130-137.

[54] Kalogirou, Soteris A. "Flat-plate collector construction and system configuration to optimize the thermosiphonic effect." Renewable Energy 67 (2014): 202-206.

[55] Cassard, Hannah, Paul Denholm, and Sean Ong. "Break-even cost for residential solar water heating in the United States: key drivers and sensitivities." Contract 303 (2011): 275-3000.

[56] Aye, Lu, W. W. S. Charters, and C. Chaichana. "Solar heat pump systems for domestic hot water." Solar Energy 73.3 (2002): 169-175.

[57] Vieira, Abel S., Cara D. Beal, and Rodney A. Stewart. "Residential water heaters in Brisbane, Australia: thinking beyond technology selection to enhance energy efficiency and level of service." Energy and Buildings 82 (2014): 222-236.

[58] Greening, Benjamin, and Adisa Azapagic. "Domestic solar thermal water heating: A sustainable option for the UK?." Renewable Energy 63 (2014): 23-36.

[59] Kontopoulos, Efstratios, et al. "An ontology-based decision support tool for optimizing domestic solar hot water system selection." Journal of Cleaner Production 112 (2016): 4636-4646.

[60] Eurostat, http://ec.europa.eu/eurostat/statistics-explained/images/2/29/Electricity_and_gas_prices%2C_second_half_of_year%2C_2013%E2%80%9315_%28EUR_per_kWh%29_YB16.png

[61] TOTEE 20701-3/2010, “National Parameters For the Calculation of Buildings’ Energy Efficiency and Issuing Certificates of Efficiency”, KENAK (In Greek)

[62] Destatis, https://www.destatis.de/EN/FactsFigures/SocietyState/Population/HouseholdsFamilies/Tables/Families.html

[63] Eurostat, http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_110a&lang=en

[64] Brander, Matthew, et al. "Technical Paper| Electricity-specific emission factors for grid electricity." Ecometrica, Emissionfactors. com (2011).

[65] Austrian Statistical Office, http://www.statistik.at/web_en/statistics/index.html

[66] Hellenic Statistical Authority, http://www.statistics.gr/el/statistics/-/publication/SAM05/2011A1602_SAM05_TB_DC_00_2011_A08_F_GR

[67] Italian National Institute of Statistics, http://www.istat.it/en/

[68] Instituto Nacional de Estadistica, http://www.ine.es/en/welcome.shtml

[69] National Institute of Statistics and Economic Studies, https://www.insee.fr/en/accueil

[70] Central Statistical Office of Poland, http://stat.gov.pl/en/

[71] Statistical Service of Cyprus, http://www.mof.gov.cy/mof/cystat/statistics.nsf/index_en/index_en?OpenDocument